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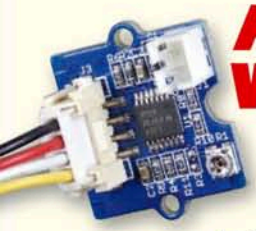

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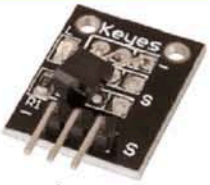

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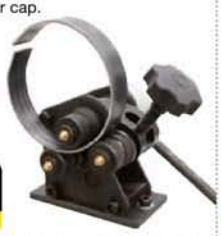

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Editorial Viewpoint

We all deserve a right to repair

In the December 2018 issue, I lambasted the European Union public service for penalising Google for anti-competitive practices. I argued that Google did more to promote competition than stifle it.

Well, this time I am going to say something nice about the EU. I applaud their new legislation giving consumers and business a "right to repair" the goods that they purchase. It is heartening to see that some people in the EU feel so strongly about this that they organised protests when it looked like the legislation might not be passed!

Several US states also have similar laws, mainly in reaction to various companies abusing the 1998 DMCA copyright act in an attempt to prevent people from fixing their own equipment. In case you are not aware, the US/Australian "free trade agreement" (AUSFTA) of late 2017 had the result of making many of the provisions of the US DMCA into Australian law. So it affects us too.

The reason why companies make devices hard to repair can be summed up in one word: money. If you can't repair your product, you'll either have to buy a new one or use their expensive repair service. Either way, they make out like bandits. And they can do all sorts of things to prevent repairs – encrypt software, use parts with restricted supply, refuse to provide service manuals etc.

But as the people promoting this new EU law have helpfully pointed out, this is a very wasteful practice, resulting in a lot of equipment being thrown away which could otherwise be repaired. And it's also a waste of money for consumers.

You only have to read this month's Serviceman column for a good example. The manufacturer wanted to charge $2000 for a new part when our correspondent was able to repair it with a $70 replacement LCD screen and a bit of knowledge and patience. See the following (short) related article: http://siliconchip.com.au/link/aanl

My biggest concern with manufacturers making it difficult for their products to be repaired is not so much the expense, but the idea that once they decide it's no longer worthwhile for them to offer a repair service for a particular product, you will have no recourse if yours breaks.

Motor vehicles are of particular concern. If you own a classic car from the 60s (say), you will generally not have much trouble fixing it if it breaks. You may have some difficulty getting new parts, but there are many companies which step in to supply replacement parts when the originals are no longer being made. So they generally are available.

But imagine if you have a classic car from the 2010s still running in 2050 (assuming we're still allowed to drive then!) and one of its many computers fails. Even if you can replace the parts which are broken, can you still get the required software? And what if you do manage to fix it, only to find that other computers in the vehicle detect the change and refuse to operate?

I would like to see manufacturers release all proprietary information about electronic and mechanical devices once they no longer offer a repair service. That includes circuit diagrams and required firmware. This information should be sufficient for a qualified third party to fix any fault. After all, if they are no longer supporting their product, they have effectively abandoned it.

Hopefully, we will get a "right to repair" in Australia some time soon!

For more information on the new EU legislation, see: siliconchip.com.au/link/aann

And for general information about the movement, see: siliconchip.com.au/link/aano

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Wanting to customise DAB+ radio interface

About your fantastic little DAB+/AM/FM Tuner project; offering pre-programmed, pre-assembled SMD kits is a great idea. But I want to be able to customise the enclosure and graphical user interface.

By this I mean customisation of faceplate, switches etc; add an RCA line output and so on. The reason for building a kit is getting it up and working in a week or two.

Customisation is why I would build a kit vs buying off-the-shelf. A pre-assembled, tested SMD PCB means fewer failures if you do not have all the SMD equipment at hand. Also, a pre-programmed microcontroller is a plus,

Regarding customisation of the graphical user interface, it would be good to have a set-up screen where you can change the colours and text fonts, add or remove menu features, the option to add a rotary encoder and tuning knob and also the option of matte black or brushed aluminium faceplates with holes pre-cut for the screen openings.

Maybe you should give the option for pre-ordering, so you know how many you need to stock.

John Crowhurst,
Mitchell Park, SA.

Response: we have already spent nearly a year on this project. Adding all the extra features you are asking for would have increased the time and cost to produce it substantially.

Since most of the code is written in MMBasic, it is easy to customise. You can do pretty much anything you want by modifying the code and the beauty is, you have a fully working set of code to start with.

You can also build it into any enclosure you want, as long as it's large enough to fit the main assembly. You can add whatever knobs and buttons you want and just modify the BASIC code to accommodate them. We've provided all the essential functions needed for a working radio. Adding many extra options would be a lot of work and would likely confuse constructors. The design is already quite complex!

The radio already has RCA line outputs. They can be mounted off-board if necessary and wired back to the PCB. The same comment applies to all the connectors.

We aren't providing fully populated PCBs for two main reasons: one, it would be too expensive and time-consuming and two, it somewhat defeats the purpose of building a kit if pretty much everything is already assembled.

We're offering boards with most of the hard parts already fitted so that any reasonably capable electronics enthusiast should be able to finish it off without too much difficulty.

Once you have built the Explore 100 module and received the partially populated PCB, it should only take a few hours to finish building the radio as described.

We have opened up pre-orders for all of the radio parts due to high demand. It doesn't help us that much with the stock situation due to long lead times, but at least people can get their orders in while the articles are still being published.

By the time this issue hits the shelves, we should have sent out most of the early orders. It will take some time to assemble all the boards for this popular project.

*You can see a list of all the items we're selling to support this project at the following link: **siliconchip.com.au/Shop/?article=11369***

App to detect atrial fibrillation

I enjoyed reading the first part of your article on Medical Diagnosis & Monitoring via Smartphone in the February issue (**siliconchip.com.au/Series/331**). A really useful daily (free) app is called "Heart Rhythm".

It uses the LED and camera on an iPhone to monitor your heartbeat at the end of a finger. For a number of years, I have suffered from occasional AF (Atrial Fibrillation), and this app has detected it every time!

Anon.

More information on poor car battery charging

J. C., of Cambridge Gardens, NSW mentioned problems with the Mazda low-voltage Q-85 battery in Ask SILICON CHIP (February 2019, pages 106 & 108). Owners of Mazda vehicles with the stop/start feature should be made aware of the vehicle's poor battery charging system.

The charging ranges between 12.0-14.6V. It occasionally charges the battery at 14.6V for a short period, then suddenly drops to the 12.0-13.0V range.

This system actually prevents the battery from fully charging. It will hold the battery as low as 12.0V for hours at a time. I have had to garage my Mazda with a Q-85 battery as the battery voltage falls to 10.1V on the restart.

I think that J. C. will find that his battery was never fully charged, and it was at 12.1V when the car was last switched off.

As the Q-85 battery costs $469.00 (not a misprint), the external charging as suggested by J. C. is necessary to prolong battery life. Now here is the idiotic situation: when you next start the engine, the system discharges the battery back to the 12.0-12.4V range in a short time.

So the external charger should be connected every time the vehicle is parked, to ensure the battery has some charge next time you start it. I have heard that some mechanics wire in a permanent socket to the bodywork for ease of connection.

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Some safety issues arise when the battery is as low as 12.0V (25% capacity). The Q-85 battery is rated at 65Ah but at this voltage, it only stores 16Ah. In cases of accidents, breakdowns or natural disasters, the reduced capacity will limit the operating time of flashers, lights, auxiliary equipment etc.

If a charging fault occurs, you would only have one-quarter of the time to travel for safety or repair. Forget about helping with a jump start.

When I travel outside of the city, I am forced to carry a spare fully-charged conventional battery as a backup because of this crazy situation.

H. Wrangell,
Elimbah, Qld.

Joseph Lucas is a modern hero

Dear Editor, I wish to complain about your Serviceman's and your own derogatory remarks in the February issue about that hero of modern automotive electronics, Joseph Lucas. Joseph, aka "The Prince of Darkness" died in 1902, but his company, like his lights, flickered on for nearly a hundred years.

It is a pleasure to drive my old Mini with only three needs; fuel, air and sparks. Mr Lucas is often blamed for the lack of the spark, but it is not always his fault.

Some modern turbo cars have water cooling sprays for the intercooler. Lucas and BMC were way ahead of their time designed a water-cooled distributor and electrical system. And since it used rainwater, you never had to fill a tank!

Rainwater is actually a poor conductor and only causes problems when it lands on dusty/dirty electrics that have not been adequately maintained. Most Minis and Morrises ended up as the family's unloved second or third car that lived outside and consequently saw more WD-40 on the inside than wax on the outside.

High-end sports cars these days often have their battery in the boot to help with front/rear weight distribution; your Serviceman did not realise that this brilliant idea originated with the Mini. The first Minis came with a "starter button" (to save money); guess what many new cars have!

I recently had to replace the "Control Box" of my car; a 1950s masterpiece of electromagnet coils and contact switches, that controls the field coil power in the generator.

It produces a PWM signal to control the output voltage and current to the battery while allowing for different air temperature, engine speed, current drain and battery charge; all without a single transistor or IC.

The replacement part is still in production in India where many thousands of British cars are still running around, like the last monotremes on a remote island in the South Pacific.

Your Serviceman has an issue with spinning metal fans; BMC Australia swapped the metal fan blades for plastic in their cars to protect your fingertips, so that you shredded your knuckles on the fins of the radiator instead.

No one in their right mind would want to daily drive a car made more than 20 years ago, given the safety and reliability advances made since then. But they do look cute and help to bring back a million memories, both good and bad.

Dave Dobeson,
Berowra Heights, NSW.

Editor's note: I have enough 'experience' with Kettering ignition systems and analog computers in cars that I never want to see one again.

Anyway, I was quite effusive in my praise of Lucas' innovation in my comments. I understand that the company still holds the patent on the short circuit.

Lucas was also a mover and shaker. He petitioned parliament in the UK to repeal Ohm's law, but unfortunately, the bill failed to pass because it met too much resistance.

On a more serious note, there are certainly advantages to having the battery in the boot which includes more room in the engine bay (to fit more engine) and heat from the engine doesn't cook the battery.

Microstepping reduces torque and positioning accuracy

I found your stepper motor articles in the January & February issues quite interesting (siliconchip.com.au/Article/11370). They both mention microstepping but neither fully explain the advantages and disadvantages of microstepping compared to full stepping.

The main advantages of microstepping are less noise and vibration from the motor and a reduced chance of resonance problems where at a specific frequency, the poles will oscillate about each other and the motor stops rotating. The main disadvantages are a dramatic drop off in torque and a reduction in positioning accuracy.

In fact, to get the best positioning accuracy, steppers should be indexed in moves of four whole steps. This is because the manufacture of the poles of the stator and rotor is not perfect.

This information comes from a white paper published

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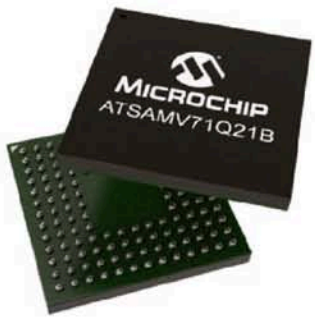

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by stepper motor manufacturer Micromo at the following link (the PDF download link is at the bottom of the page): siliconchip.com.au/link/aang

The stepper motors that Micromo sell are tiny. I never realised that such small motors were available.

George Ramsay,
Holland Park, Qld.

Star tracking with one rotation per sidereal day

I read Graham Jackman's Circuit Notebook contribution in the January issue on modifying the star tracking mechanism in a Celestron telescope (pages 94-96).

I don't know if he was simplifying things for us, but the Earth rotates relative to the stars in about 4 minutes less than 24 hours, so to fix the stars in its view, the Celestron base would have to complete one full rotation in that period.

Based on the figures he has given, to achieve that would require a stepper motor drive pulse rate of 8.5353Hz (~32,768Hz ÷ 3839). Eliminating diode D5 gives 3840 which is probably close enough. But maybe the Celestron gearing was designed to take a final drive of 15RPH to give one revolution in one sidereal day, not one solar day.

Alan Cashin,
Islington, NSW.

Response: Graham's text noted that the motor he replaced claimed to rotate 15 times per hour, so his replacement circuitry was designed to drive it at that same rate.

We assume that the telescope gearing compensates for the sidereal day by careful selection of the number of teeth in the gears. We asked Graham for comment and this is his response:

It's difficult to be sure as the difference is only 0.3% and while it might be necessary for long photographic exposures, I have never made one that long.

In any case, unless you have the polar alignment perfect, there will be some residual drift. With a rough and ready setup, the telescope tracks very well and only occasional adjustments are necessary.

I initially assumed that it would have 360 teeth and the frequency obtained would be in error by about 0.25% or around 3 minutes a day. This seemed to agree with what I found after letting it run for 24 hours. If finer corrections are needed, the diode arrangement could be changed.

For the volunteers at Scienceworks, this has allowed us to use the telescope when the goto Meades are hard to align because of poor viewing (clouds seem to follow our Discover The Night Sky program).

We can let the general public use this one without having to monitor it constantly and it's very easy to realign with new objects.

Making emergency calls post-NBN

I have just read the letter titled "Back to base security systems and the NBN" in the January 2019 issue. I used to work for one of the telecommunications carriers in the provisioning, operations and maintenance areas.

Recently we were notified that the NBN rollout in our area would be completed by the end of February 2019. We currently have a copper phone line with ADSL for the internet.

The letter from the NBN said that we would be connected to the HFC network. In the letter, they mentioned that the HFC network would not work during a power outage, even if you kept your equipment powered using a UPS or battery.

The telephone exchanges I worked in could usually run for 4-24 hours from batteries, giving plenty of time to start the standby diesel generator. It had enough fuel to run the exchange and provide air conditioning for three to four days; longer if more fuel could be obtained.

We took the attitude that the copper telephone service was a "safety of life service" and so needed the absolute best uptime.

As my wife and I are no longer spring chickens, I bought a wireless alarm pendant. If my wife or I fall or need urgent help, we can press the button and the phone dials a list of numbers until someone answers. This phone has batteries which last 48 hours if the mains power fails.

When I rang the NBN about this, all they could say was to have a fully charged mobile phone available in case the mains fails so that you can make a phone call.

As most of you would know, by the time you get home at the end of a day's work your mobile usually needs charging. I was not amused at the idea of having pay for another mobile phone plan just because the NBN won't work during a power outage.

This brings up the question: how

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long will the 3G/4G network operate in the event of a mains failure? Even if your phone is charged, it's no good if the local towers have lost power.

I have rung Optus, Telstra & Vodafone and they all just said that the towers could run indefinitely if the mains fails. I find that hard to believe.

They would not let me talk to their technical staff to find the real answer. Through a friend who knows someone in Telstra, I was told that the current Telstra base stations would run for a maximum of three hours on a good day.

I heard second hand that during the bad storm in December 2018, the base stations in Cherrybrook and Galston were off the air for more than two days but I have not been able to confirm if this was due to power failure or storm damage.

In summary, the move to the HFC NBN is a massive backwards step from a reliability point of view. It seems if the power fails, I will lose the landline telephone immediately and then the mobile network after around three hours, possibly sooner if the network is overloaded as a result of the NBN going out.

How then am I to call for help in case I need a 000 service more than three hours after the mains fails?

David Williams,
Hornsby, NSW.

Response: that's an excellent question. Perhaps a reader can give us a good answer. We were not amused when our office phone lines failed for 24 hours a few months after we were forced to switch to the NBN.

The old copper system never had that problem. We had to reboot our router to get the phones back. We only found out they were down when customers complained they couldn't reach us!

In the meantime you can try looking into priority assistance: siliconchip.com.au/link/aanh

Telstra is the only provider that is required to provide this, but unless you're on FTTP there's not a lot extra they can do other than give you priority for repairs. Your only other options are to invest in a pager or a satellite phone.

Help to identify a shuttered manufacturer

I have been given a Datasaver 2 UPS that still works. I want to find out who made it and if it could be adapted to lithium batteries, as I use these in motorcycles.

The unit was made by a company at 445 Macquarie Street, Hobart, Tasmania. When I looked up this address on Google Maps, it was an empty factory that was up for sale.

The phone number on the label is a very old one: 002 23 4263. Can anyone give me details on this piece of equipment, put me in touch with the company or tell me of someone who may know about them?

Would it also be possible for you to design a project that could be fitted to motorcycles to allow them to safely use lithium batteries?

There have been several incidents when people have tried to do this. Some bikes have burned to the ground, despite using batteries designed for use in motorcycles (Motocell brand). This can be a very expensive experience with sports bikes costing up to $40,000.

Peter Allica,
Yinnar, Vic.

Response: if anyone has information for Peter, please e-mail us at silicon@siliconchip.com.au

We would be reluctant to use any lithium-ion battery in a vehicle unless it was $LiFePO_4$ because batteries in automotive applications can get very hot and LiPo/Li-ion batteries can fail spectacularly.

$LiFePO_4$s are much more robust and don't explode or catch fire when they fail. See our article on them in the June 2013 issue (siliconchip.com.au/Article/3816).

We are surprised that batteries claiming to be suitable for use in motorcycles appear to have virtually no protection circuitry. You should avoid that brand entirely.

We don't suggest you try to adapt any other kind of batteries for automotive use. SSB Lithium Ultralite batteries should be safe. See http://siliconchip.com.au/link/aan7

Using a Raspberry Pi to play videos

Like many these days, we have an extensive DVD collection that's grown over the years. A while back, I decided to recycle a PC for use as a Plex server and rip our DVD collection to MPEG4 files, our many CDs to FLAC audio format and also to add all our digital photos to the server.

That computer has now been superseded by a recent Gumtree find, a

QNap NAS box with 12TB of storage.

I first tried an Android-based box for playing the video and audio files and viewing the photos. But it was slow and clunky, and not terribly reliable, with quite a few slowdowns and lockups.

So I switched to a Raspberry Pi 3 running a dual boot of LibreElec and RasPlex. This works very well indeed, but has a few minor shortcomings.

First off, the Pi has no real power switch, and secondly, there is no way to remote control Plex or LibreElec that's suitable for my family to use. How about a project using a Raspberry Pi 2 or 3, running a version of Kodi with a custom power switchboard and infrared remote control?

A learning function for the IR remote would be handy, as would a nice custom case with PWM fan cooling and an easy-to-use power switch. More features could be added, of course, like a SATA hard drive interface etc. But I think just the power switch and learning IR remote control would be a great start.

Raff. Lerro,
Gold Coast, Qld.

Response: that's an interesting idea that we will look into.

Good experience with Banggood

I must respond to the letter from John Evans, published on page 8 of the February 2019 issue, regarding dissatisfaction with Banggood's after-sales service. Over the last few years, I have ordered several items from Banggood. All have arrived safely after variable delays due to postal services etc with only one exception.

I received an incorrect item about a fortnight ago. Communications with Banggood via their chat service quickly rectified the problem, and after providing the requested information (copy of initial order, scanned copies of postal information and photograph of the received item), the item was replaced by post. The replacement item arrived in good working order.

Col Hodgson,
Wyoming, NSW.

Manufacturing problem with some AD9833 modules

I have finished construction of the Superhet Alignment Generator (September 2017; siliconchip.com.au/Article/10799) using parts ordered from your Online Shop, including the Micromite LCD BackPack kit and AD9833 DDS module. While the Micromite module is working correctly, there is no signal coming from the DDS module output.

Fortunately, I had previously constructed the DDS Signal Generator (April 2017) and this unit works perfectly. I therefore connected the DDS module supplied with this order in place of the known good DDS module on the DDS Signal Generator and there was absolutely nothing coming out of the new DDS module.

While the two modules look similar, the non-working unit has less clear screen printing on the PCB, and it does not have AD9833 printed on it as does the working unit. I am guessing they are from different manufacturers.

The working unit has a clock oscillator with a big "25MHz" printed on it while the dud module has "TXE EBc73" printed on it and "25.000" on a second line of text.

I decided to measure the SMD resistors on the two modules and found that the four resistors closest to the pin header (between CLK and FSY) all measure 100Ω on the good board and 10kΩ on the bad board. Close inspection with a magnifier shows the resistor arrays are marked 101 and 103 respectively. That's a pretty big difference and would play havoc with the control signals.

Geoff Graham's suggestion was to just remove the 10kΩ resistor array and replace the four resistors with wire bridges. I did that and the module now works.

You need a steady hand and a good magnifier. Liberal application of liquid soldering flux (washed down later with isopropanol), pre-tinning the board pads and the fine wire used for bridging plus a fine tipped soldering iron ensures a good result.

Ross Herbert,
Carine, WA.

Response: we went through our stock of modules and checked. Bizarrely, not only did we find modules with 100Ω and 10kΩ resistors as you did, we even had some modules with 1kΩ resistors! It's almost as if the manufacturers are just throwing whatever component they can get on there, regardless of value.

Presumably, these modules would all work as long as the drive frequency was low enough, depending on the resistor values.

We'll be on the lookout for this in future and reject shipments from suppliers that have the incorrect values. We'll replace the 1kΩ and 10kΩ resistors with 100Ω resistors for any of the modules we currently have.

Low coolant alarm is a good idea

The letter asking about how to build the Coolant Alarm described in 1994, on page 110 of the February issue, prompted me to write to you regarding my experience with that project.

Back in the early 1990s, I destroyed the engine in my car due to a leaking

radiator, resulting in severe overheating. A year or two later, SILICON CHIP published the Coolant Level Alarm project. I built one and fitted it to my new car to prevent re-occurrence and have fitted them to all my cars since.

My son borrowed my 2000 Nissan Pathfinder during Christmas 2018 and I received a phone call asking what the beep and LED flashing on the dash was. I asked him to check the coolant level. It was low but not empty so costly engine failure was avoided. It turned out to be a faulty radiator cap which was easily replaced.

I also built a Coolant Level Alarm for my son-in-law as his father had lost an engine due to a blown radiator hose. He rang me one day and said his father was not happy as he had blown another engine due to a coolant leak and my Coolant Alarm did not go off.

After he let me stew for a while, he added that his dad had not got around to fitting it! It's a great project and I still use it to this day.

Fred Wild,
Airport West, Vic.

Other approaches to a Low Coolant Alarm

Back in the 1970s, National Semiconductor produced an IC specifically for use as a low coolant level alarm in vehicles: the LM1830N.

For 35 years I have used this chip in cars, trucks and tractors to give an alarm on low water level in the radiator, and at least one is still in use today, working well. I have not had a fault or false indication yet. I still have spares for future use.

The circuit for using this chip was published in the NatSemi 1982 Linear Handbook. It has only a couple of components mounted onto a small circuit board and built into a tiny Jiffy box, mounted under the dash. I added a transistor and buzzer for an alarm. For the sensor, I use a small spark plug with the bent electrode broken off, mounted in a brass socket soldered mid-way into the radiator top tank.

On turning on the ignition it gives a brief buzz, indicating that it is in operation and functioning correctly, then only produces an alarm if the water level is low.

This IC had such a low oscillator output level (AC) that I also made several bed wetting alarms for young children, and it worked exceptionally well. Two minuscule probes mounted in a nappy or pad and not in contact with any skin achieved an instant result.

Sadly, the LM1830N is no longer manufactured but does appear on eBay at exorbitant prices.

In its day, National Semiconductor was regarded by me as second to none in quality, and I do not remember a single failure, not like the last 10 years where every component has to be regarded with suspicion.

I seem to remember *Electronics Australia* producing a minimum count discrete component version of a water level detector that achieved the same job, but I have not checked.

I have been a reader of *EA* and SILICON CHIP for some 60 years and built many projects. Thanks for the excellent magazine.

Denys Cooper,
Laura, SA.

More failing motor capacitors

The over-current device tripped on one of my air conditioners during the recent heatwave. On the next day, not so hot, it did it again even at a higher temperature setting and so I checked the capacitors and found the motor run capacitor to be open circuit.

One clue was that the compressor sounded wrong; the wow-wow sound of the induction motor, as the rotor slipped relative to the 50Hz supply, was faster than usual. I replaced the capacitor with a new one but thought I should check the capacitors on my two other air conditioning units and found that they were both well below their rated values.

Having been involved more with low-powered electronic devices over the years, my impression of old capacitors was that the foil type capacitors generally held their values as they age and so I was surprised to find these failed. Run capacitors are always foil type (once called paper) capacitors, either oil filled or dry. My guess is that they have partially delaminated.

The rather cynical trade supplier I purchased the new ones from thought I was lucky to get more than a couple of years' life out of a motor capacitor. He thought of a capacitor rather like a battery going flat from the moment it started in life.

I wonder how many other air conditioners are running with below-specification capacitors. These motors will be running hotter than normal which will cause the insulation to deteriorate quicker, and so shorten the life of the motor. A quick check might put off the need to replace a compressor.

Ken Moxham,
Urrbrae, SA.

Comment: all components have a finite lifespan, but motor capacitors have a pretty harsh life, with high inrush currents and high operating temperatures, as well as being exposed to power spikes. It isn't surprising that they need occasional replacement, although we suspect many such capacitors are low quality and so fail prematurely. SC

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Medical Diagnosis and Monitoring via Smartphone

Part 2 – by Dr David Maddison

Last month we looked at some of the newest Smartphone Apps requiring little or no "extra" hardware to measure, record and even diagnose ailments. But there's a host more apps which work with some add-ons to the smartphone.

Some medical diagnostic applications require capabilities beyond that provided by a phone's built-in hardware, so an external electronic device is required.

This can interface with the phone via wireless (such as Bluetooth or WiFi), or it can plug into a wired port; eg USB or Apple's Lightning.

Detecting cancer with an "artificial nose"

There are a number of claims, dating back to a report in "The Lancet" in 1989, that a dog can be trained to detect certain forms of cancer which are revealed by a distinctive smell of the breath, perspiration or urine.

These are apparently caused by chemical compounds generated by the tumour.

While some people are sceptical of such claims, based on this idea, Israeli scientist Professor Hossam Haick set about in 2007 to develop the Na-Nose (short for Nano-artificial Nose).

This device is modelled on the olfactory system and brain of a dog so that it can detect, via a breath sample, diseases such as certain cancers, Parkinson's disease, multiple sclerosis, Alzheimer's, gastric ailments, kidney disease and others (Fig.12).

Each disease produces a unique "breathprint". The idea is to be able to detect disease conditions early, before a patient is even aware of them, when much more effective treatment can be given.

The Na-Nose uses nanotechnology, with gold nanoparticles and carbon nanotubes making up part of the sensor.

These nanoparticles and nanotubes are coated with organic ligands. A ligand can form a complex in the presence of specific organic molecules,

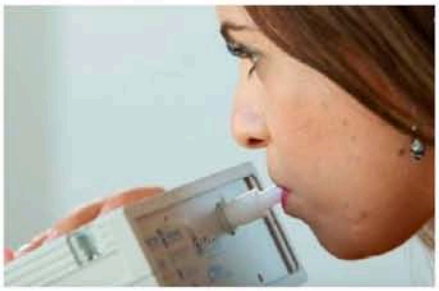

Fig.12: a patient's breath being sampled by the handheld Na-Nose. ***Image source: Technion.***

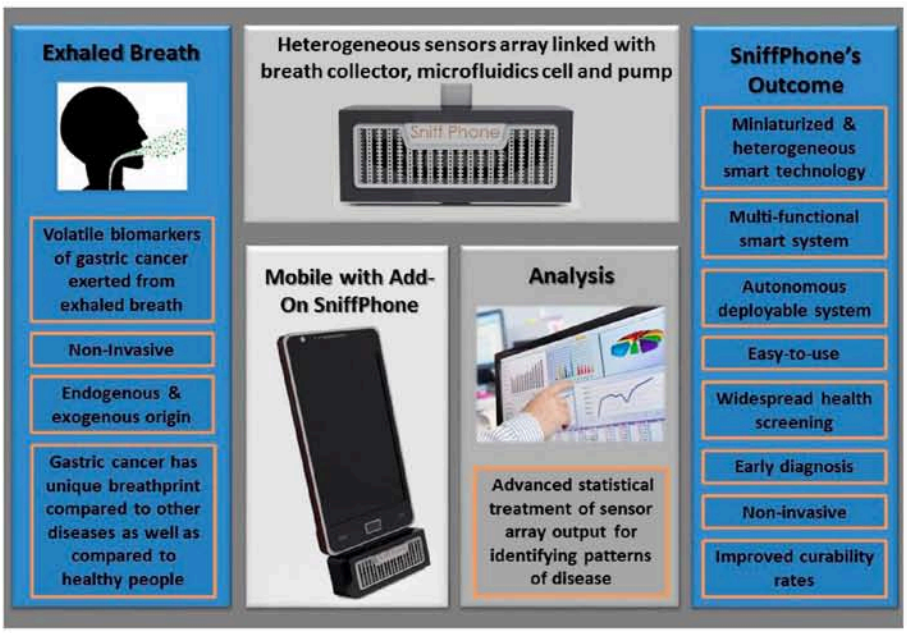

Fig.13: a panel showing the SniffPhone features.

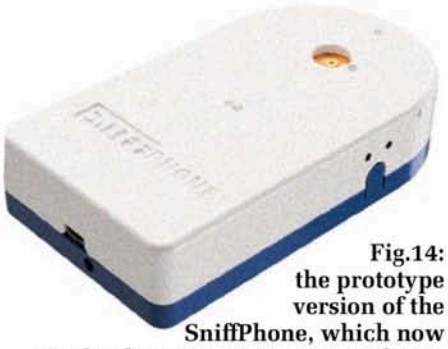

Fig.14: the prototype version of the SniffPhone, which now wirelessly connects to a smartphone.

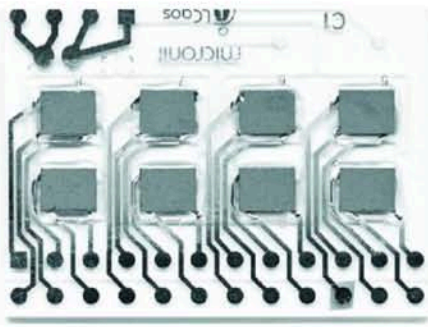

Fig.15: the prototype Na-Nose and SniffPhone sensor array.

changing its properties and this change can be detected.

When a molecule of interest is detected, the electrical resistance between the nanoparticles or nanotubes changes and the resulting signal is analysed.

Pattern recognition software in the computer, which has learned various disease signal patterns from machine learning, is then used to diagnose the disease.

The Na-Nose was initially trained to detect 23 diseases and was used in 19 hospitals worldwide, with 8000 patients to teach its machine learning software.

In follow-up trials, it was found to detect gastric cancers with 92-94% accuracy and it could also detect 17 different diseases in a trial of 1404 people with an accuracy of 86%.

You can see a video with more details, titled *"Detecting Disease Through Breath Prof. Hossam Haick Technion"* at: **siliconchip.com.au/link/aamq**

The plan is now to miniaturise the Na-Nose to create a device called the SniffPhone, which will be used as a peripheral for a smartphone.

The SniffPhone (**www.sniffphone.eu/**) is under development lead by Technion-Israel Institute of Technology's professor Hossam Haick, with a consortium that includes several European companies (Figs.13, 14 & 15).

See the video called *"Sniffphone, a Phone So Smart It Sniffs out Disease - Hossam Haick -Technion"* at: **http://siliconchip.com.au/link/aamr**

Portable DNA analysis

Q-POC is a system under development by UK-based QuantumMDx (**siliconchip.com.au/link/aams**). This device will give DNA analysis within 10-20 minutes of taking a sample from a patient.

The device looks for specific DNA markers associated with certain diseases, or susceptibility to certain drugs.

It amplifies DNA using PCR (the polymerase chain reaction) – all in a handheld device! (Fig.16)

It can be used to determine if a patient is sensitive to a particular drug or not and whether it may have adverse effects if it is administered.

It can also determine drug susceptibility for treatment of tuberculosis, sensitivity to warfarin anticoagulant and provides rapid detection of certain infections that otherwise would take 48 hours of laboratory tests. It can also detect asymptomatic cases of malaria, so that drugs can be given early during the onset of the disease.

This device will have many applications for a variety of health professionals, including in a doctor's office in Western countries, and for field workers in developing countries without healthcare infrastructure.

The tests will be cheap and reliable. The initial target price for the device is £1,000 (~AUD$1750) with a cost per test of £3 (slightly more than AUD$5).

The release date was initially expected to be 2018 but as of January

Fig.16: the QuantumMDx Q-POC device, currently under development.

Wound Analyser App

Further to our look at diabetes-related smartphone apps in part one of this feature, as we went to press an article appeared in "New Atlas" on a smartphone app which would give much more consistency in the treatment of diabetic ulcers and wounds.

It's called "Swift Skin and Wound" and was developed by Dr Sheila Wang at McGill University in Montreal, Canada.

One of the (many!) side effects of diabetes is the significant slowing of the body's ability to repair damage due to lower blood flow to the wound site. Normally, increased pain would alert patients/clinicians to problems but a lack of nerve endings in many diabetics means wounds might go untreated.

Traditionally, wounds have been analysed simply with a ruler to check whether they are increasing, remaining the same or diminishing. It's an imprecise system, relying on judgement which has been unreliable.

Swift Skin and Wound uses an iPhone camera to compare the current area of a wound to a marker of a known size, which is placed on the skin. It can additionally incorporate a phone-mounted FLIR infrared camera, which can detect infection via increased skin temperature.

In use by Montreal's McGill University Health Centre (MUHC) since 2016, the app has been shown to produce more consistently accurate readings than a ruler and to be as accurate as a measuring tool known as a digital planimeter. Unlike a planimeter, however, the app allows clinicians to store and track measurements over time, and to share them with physicians in other locations via the internet.

This could be a particularly valuable feature in remote regions, where high staff turnover means that multiple successive clinicians end up tracking the same wound.

Swift Skin and Wound* uses a smartphone camera to take images of a wound against a marker placed on the skin. As well as being much more precise, images can be stored and/or transmitted to a specialist.** *See* ***siliconchip.com.au/link/aamt

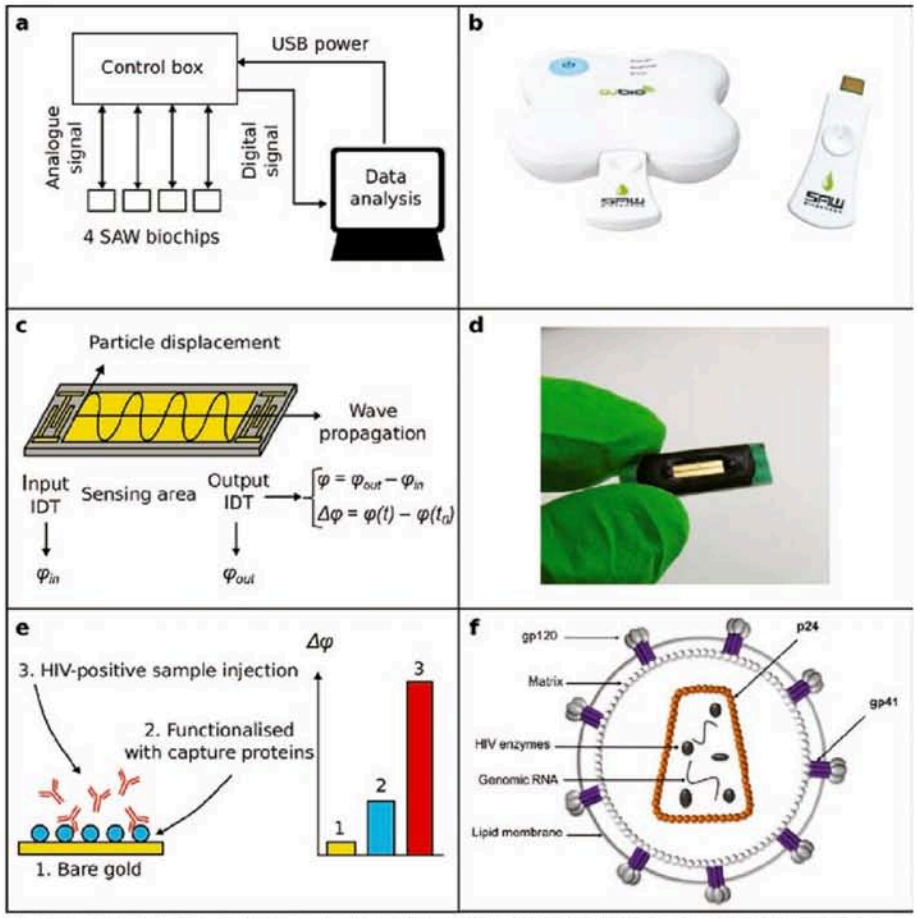

Fig.17: HIV detection using surface acoustic wave (SAW) sensors in around 10 seconds. (a) prototype configuration (b) image of prototype (c) a phase shift is generated on the SAW device due to the presence of the virus particle, which is measured (d) the disposable SAW chip (e) How the SAW biochip captures HIV particles on special capture proteins, leading to a phase shift (f) HIV structure. ***Image source:*** ***www.nature.com/articles/s41598-017-11887-6***

2019 there has been no news of its release.

For more information, see the video titled *"Inside Q-POC: Translating genetic code to binary"* at: **siliconchip.com.au/link/aamu**

Virus detection

Scientists at the University of Surrey (England) have developed a 10-second HIV test using disposable surface acoustic wave (SAW) biosensor devices that plug into a smartphone.

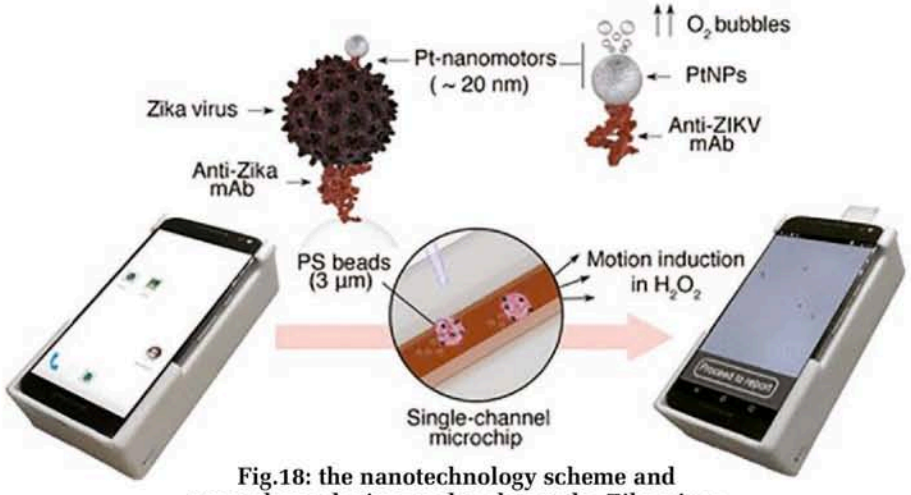

Fig.18: the nanotechnology scheme and smartphone device used to detect the Zika virus.

The device uses blood from a finger prick and no processing of the sample is required.

SAW devices generate acoustic waves by piezoelectric means and the presence of a mass on the device (such as captured virus particles) causes a change in the properties of the acoustic signal which can be measured. The mass can then be determined, leading to the identification of the substance under test (Fig.17).

Zika virus

Another virus which is being heavily researched is the Zika virus. It is a significant public health concern as it can cause severe complications in infants if their mothers catch the virus during pregnancy.

The virus mainly affects third world tropical countries but there have been cases of travellers bringing the disease back to Australia.

Researchers at Brigham and Women's Hospital in Boston, USA (**siliconchip.com.au/link/aamv**) have developed a smartphone-connected device that uses nanotechnology to cheaply and easily detect the virus. This will be especially welcome in countries that cannot afford more expensive diagnostic technology.

The device is intended for use both by both medical professionals and for couples who are trying to conceive. Virus diagnostics are frequently based upon detecting antibodies in the blood, however, in the case of Zika, similar viruses such as dengue can elicit the same response, leading to false positives.

To solve this, the Brigham and Women's Hospital team have developed a completely non-conventional approach.

They developed polystyrene (PS) microbeads (3 microns diameter) that have an affinity for the virus, as well as platinum (Pt) based nanomotor structures that also have an affinity for the virus.

(A nanomotor is a molecular-size motor made from atomic components.)

Both the beads and the nanomotors have Zika-specific antibodies attached to them.

When the virus attaches to the microbeads and the nanomotors in a hydrogen peroxide (H_2O_2) solution, the motion of the Zika, bead and nanomotor complex can be detected using a microchip and the camera on a

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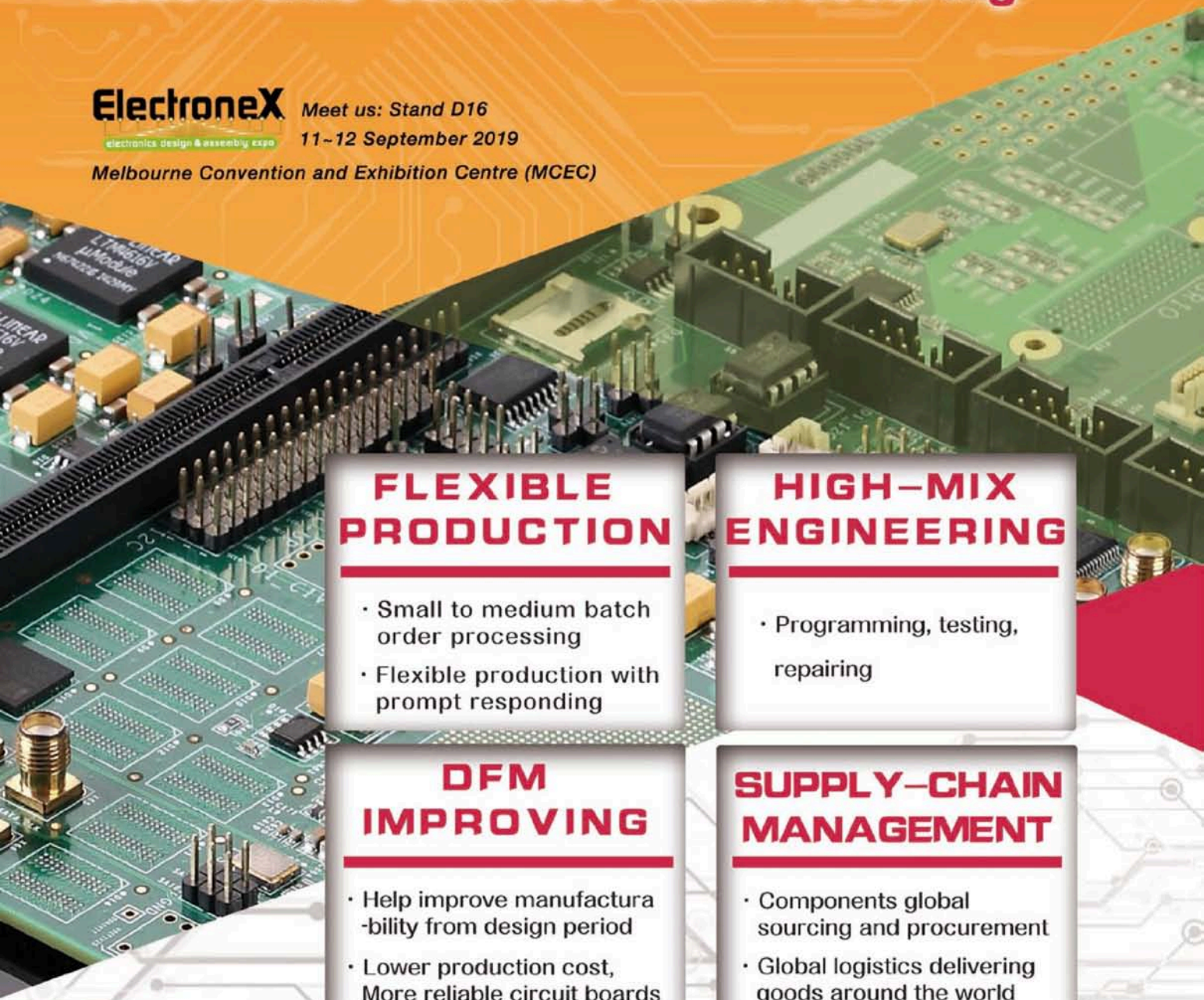

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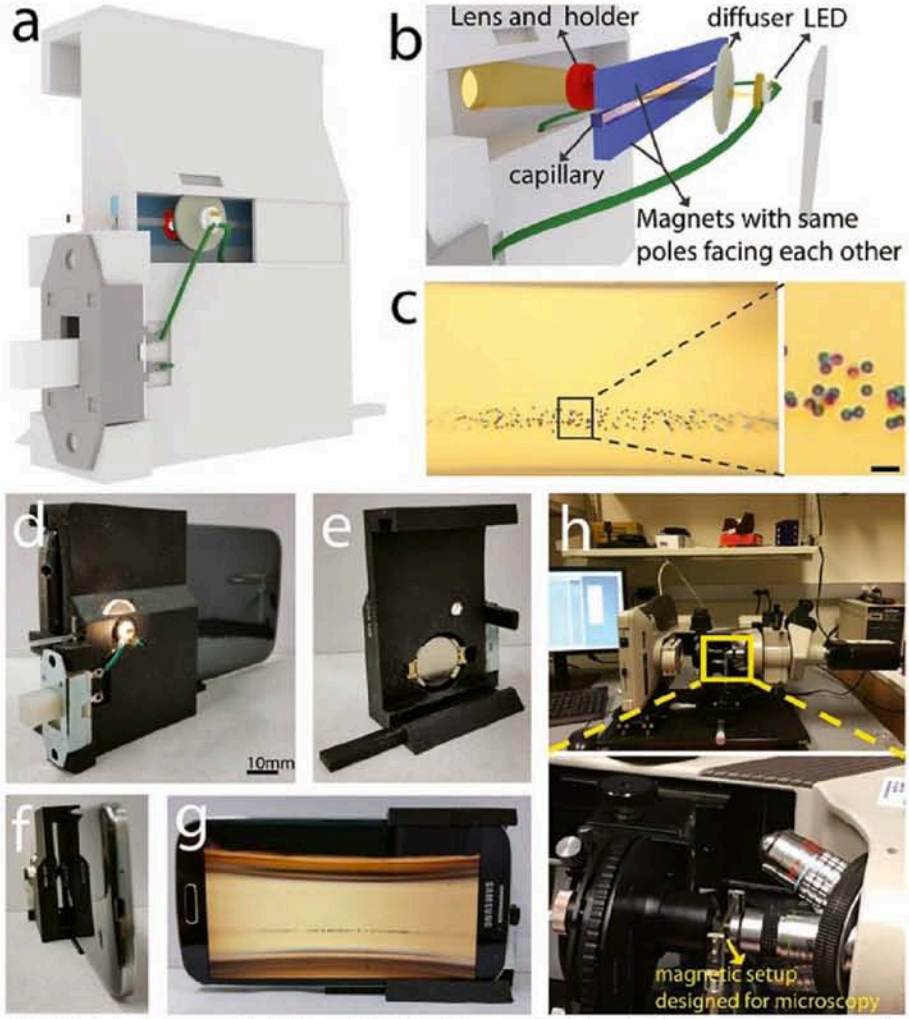


Fig.19: (a) diagram of sickle cell tester (b) sample illumination and magnets (c) 10 micron diameter microspheres undergoing magnetic levitation (d,e,f) various view of the 3D-printed prototype (g) image of magnetically levitated spheres on a smartphone (h) a conventional microscope laid on it side, doing a similar job. ***Image source:*** ***https://doi.org/10.1038/srep15022***

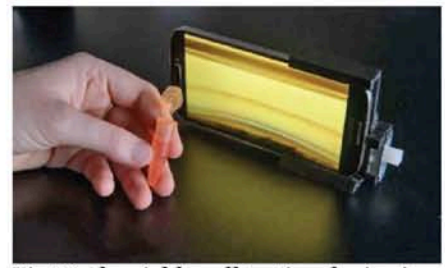


Fig.20: the sickle cell testing device in use. It is a similar size to a smartphone.

Fig.21: prototype blood-pressure monitoring smartphone peripheral, mounted on the back of the phone.

smartphone (see Fig.18).

Other viruses in the solution move much slower than the Zika virus, so the faster-moving Zika complex can be distinguished.

The sensitivity of the technique is such that one virus particle per microlitre can be picked up.

The technology is called the "nanomotor-based bead-motion cellphone" (NBC) system and could potentially be used to detect other viruses in future

Detecting sickle cell anaemia

Scientists at the University of Connecticut (US) and colleagues from Yale, MIT and Harvard have developed an experimental smartphone-based device to perform quick, inexpensive tests for sickle cell disease.

The test relies on the fact that the deformed blood cells have different magnetic properties to normal blood cells and when placed in a magnetic field in a special solution, will levitate to a different degree (Figs.19 & 20).

The device will have particular applicability in Africa, where there are few medical testing facilities and the disease is common.

See: **siliconchip.com.au/link/aamw**

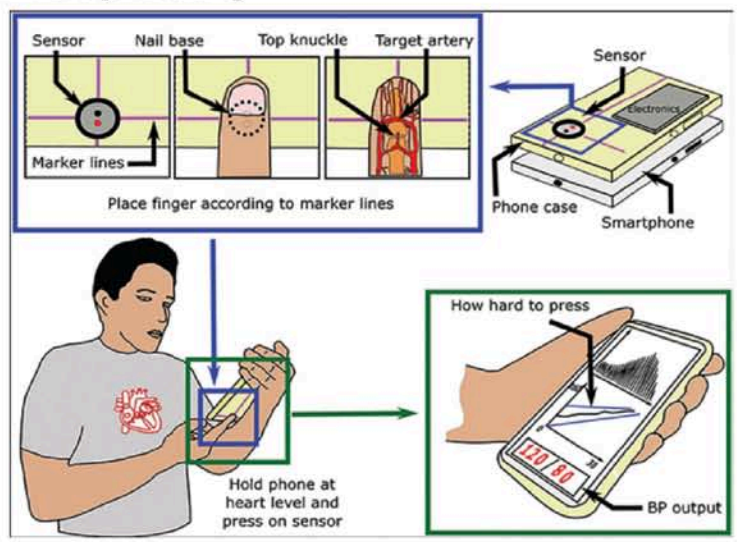


Fig.22: how blood pressure is measured with a smartphone and associated peripheral.

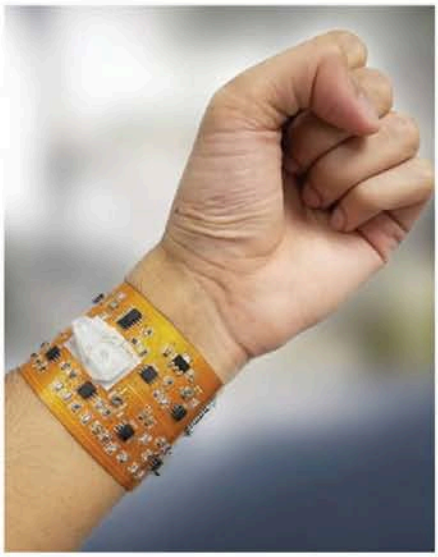


Fig.23: a prototype of the flexible microfluidic cytometry wristband. *Image source:* *https://doi.org/10.1038/s41378-018-0019-0*

Fig.24: the Apple Watch Series 4 smartwatch with cardiac monitoring feature.

Blood pressure monitoring

Researchers at Michigan State University (USA) siliconchip.com.au/link/aamx have recently developed a smartphone peripheral and app that measures blood pressure at the finger.

It uses a force and optical sensor, which works on the same principle as a cuffed blood pressure measuring device.

It allows for blood pressure to be quickly and easily tested with reasonable accuracy. The peripheral communicates with the phone via Bluetooth (Figs.21 & 22).

For more details, see the video titled *"This modified smartphone measures blood pressure directly from your finger"* at: siliconchip.com.au/link/aamy

There are also many other commercial smartphone-connected blood pressure monitors on the market which interface to a smartphone, however, all of these use a traditional cuff. They includes the QardioArm, Omron Evolv, Kinetik Bluetooth blood pressure monitor, Pyle PHBPB20, Omron 10 Series and iHealth Feel.

Tracking blood counts (cytometry)

Cytometry involves the determination of the physical and chemical characteristics of cells such as blood cells. Cytometry can be used to provide significant insights into a patient's health

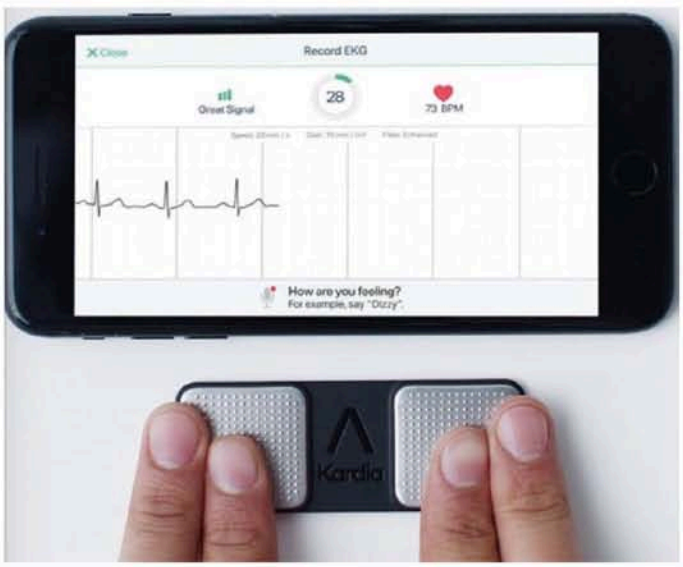


Fig.25: the AliveCor KardiaMobile ECG App and its associated hardware. Now available in Australia, it consists of a device and app that enables you to record and review electrocardiograms (ECGs) anywhere, anytime. The device attaches to the back of most iOS and Android devices, and communicates wirelessly with the free Kardia app, providing powerful display, analysis and communication capabilities.

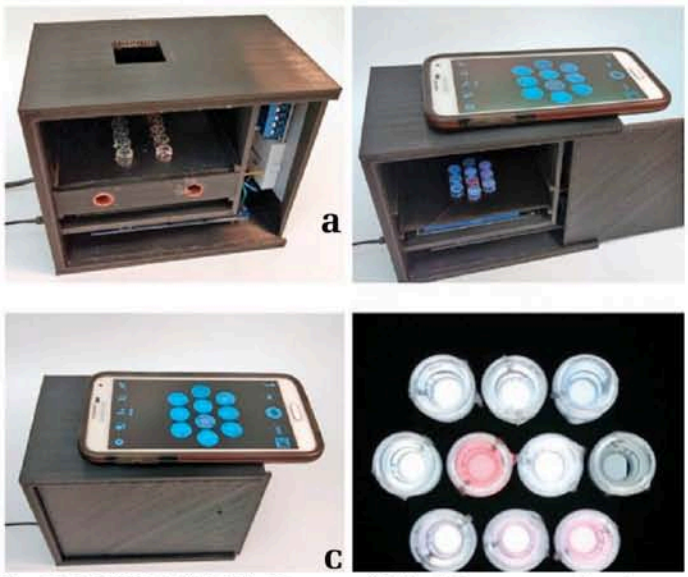


Fig.26: MELISA (Mobile Enzyme-Linked Immunosorbent Assay), a mobile version of the gold standard for laboratory biochemical analysis (ELISA). This prototype enclosure is 3D printed and the incubation function is controlled by an Arduino. The light to illuminate the sample trays is provided by an LCD screen. Image capture is done with a smartphone. Usually, the door of the MELISA is closed for image capture but is open here for demonstration purposes.

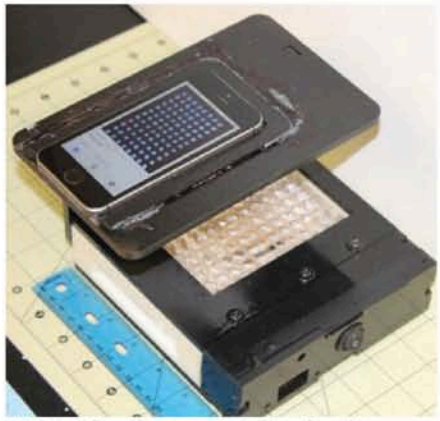


Fig.27: the prototype mReader. It contains 96 sample wells which change colour if a particular biomarker is present. The smartphone detects and analyses that colour change.

such as measuring white or red cell counts or platelet levels.

Researchers at Rutgers University (see siliconchip.com.au/link/aamz) have developed a wearable wristband that performs flow cytometry via a microfluidic device that analyses a sample of tiny amounts of blood.

Many other biomarkers in the blood such as proteins and nucleic acids can also be sensed (Fig.23).

Data is sent to a smartphone and then possibly to a central database.

The device can be used to monitor the health of patients on a continual basis, such as those undergoing chemotherapy, to ensure their blood counts remain at an acceptable level.

Cardiac monitoring

The Apple Watch Series 4 can monitor cardiac activity such as heart rate and it also has basic ECG (electrocardiogram) functionality.

Fig.28: the TRI Analyzer, showing a cartridge with multiple samples being inserted into the device.

The ECG measures the electrical activity of the heart and the apple Watch does this by making a connection between the watch on the wrist on one side of the body and a finger of the opposite side of the body, held to the crown of the watch (Fig.24).

This is equivalent to a single-lead ECG, as opposed to the traditional 12-lead ECG used in hospitals and by medical staff.

An app associated with the watch can detect normal sinus rhythm and a condition known as atrial fibrillation which requires urgent medical attention.

(We published a DIY ECG project in the October 2015 issue; see siliconchip.com.au/Article/9135).

The AliveCor (www.alivetec.com/) KardiaMobile ECG app and hardware is a single-lead ECG monitoring device that works with smartphones (Fig.25). Like the Apple Watch, it can warn of atrial fibrillation.

A recent study by the Intermountain Medical Center Heart Institute in Salt Lake City (USA) found that the app could also be used to diagnose a type of heart attack known as an ST-Elevation Myocardial Infarction (STEMI), in which a major artery to the heart is blocked, almost as accurately as a 12 lead ECG.

Fig.29: the DxtER kit with peripherals and tablet. It has been developed to diagnose 34 conditions including diabetes, atrial fibrillation, obstructive pulmonary disease, urinary tract infection, sleep apnea, stroke, tuberculosis, pneumonia and more.

In the study, the device was moved around the body to record the same signals as a traditional 12-lead ECG.

Mobile lab-quality tests

The Mobile Enzyme-Linked Immunosorbent Assay (MELISA) is a prototype mobile version of the gold standard of laboratory biochemical analyses, ELISA, which has been developed by researchers at the University of South Florida (see Fig.26).

The device incubates samples in a medium which changes colour according to the amount of sample under test. The colour change is analysed by the camera on a smartphone, to measure the amount of the substance of interest.

The device has been demonstrated measuring the female hormone progesterone and is being developed to

Fig.30: Dynamic Biomarkers' Tricorder device showing smartphone interface and drawers of the unit showing various diagnostic accessories.

Fig.31: the My UV Patch. It is about the size of a 50c piece and half the thickness of a human hair. Different parts change colour according to the UV exposure received. The patch contains flexible electronics that store a unique ID.

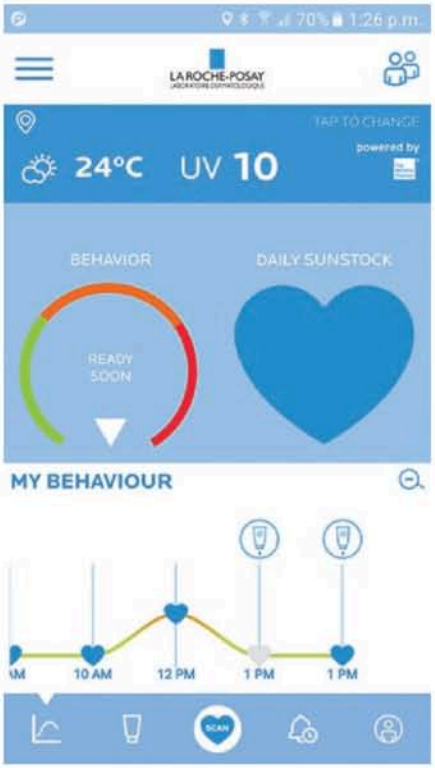


Fig.32 (left): the smartphone App which reads the My UV Patch.

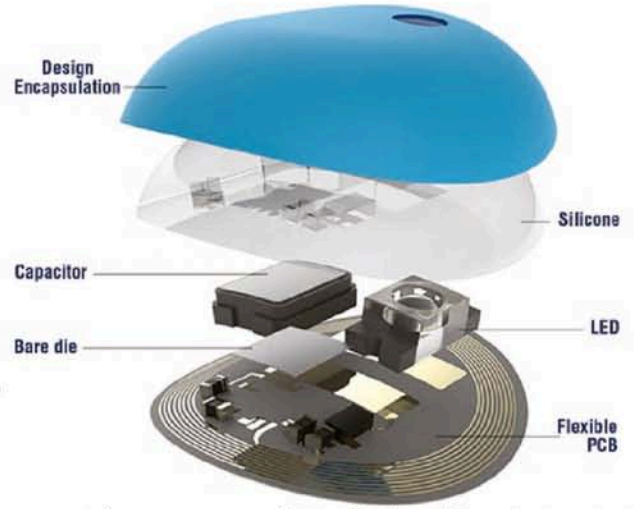


Fig.33 (right): "exploded" view of UV Sense device which is attached to the thumbnail. It is 2mm thick, 9mm in diameter and can be worn for up to two weeks at a time.

measure other substances.

It is expected to be used in applications such as clinics in remote areas and third world countries. The device and tests are very much cheaper than the equivalent ELISA equipment and tests.

Similarly, mReader (mobile reader) is a prototype device from the Washington State University and University of Pennsylvania, designed primarily for use in third world countries, which can simultaneously check 96 different patient samples for 12 different bacterial or viral infections (see Fig.27).

Diagnosis is made by colour changes which are detected by a smartphone. The patient samples are deposited in specially treated wells with reactants that undergo a colour change in response to the presence of certain viruses or bacteria.

Portable spectrometer

The TRI Analyzer was inspired by the fictional Tricorder from Star Trek. TRI stands for transmission, reflectance and intensity.

It was developed by scientists at the University of Illinois at Urbana-Champaign. It is a spectrometer and can perform common laboratory tests on blood, urine and saliva samples (see Fig.28).

The device can be used to perform any standard biochemical test that produces a colour change or generates light in the form of fluorescence, such as the standard ELISA test (enzyme-linked immunosorbent assay).

The 3D-printed device uses the smartphone's flash as a light source or uses a laser diode to illuminate a test sample and the light from the sample is guided via optical fibres through a diffraction grating to the smartphone camera.

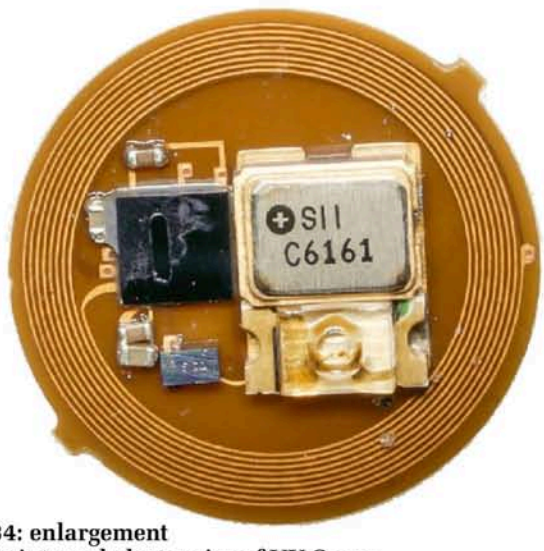
Multiple samples can be tested in one session, by pushing a cartridge containing the samples through the device.

General health diagnostics

DxtER (www.basilleaftech.com/dxter/) was originally developed to win the Qualcomm Tricorder X-Prize (see panel last month) but has now been developed to diagnose 34 conditions including diabetes, atrial fibrillation, chronic obstructive pulmonary disease, urinary tract infection, sleep apnea, leukocytosis, pertussis, stroke, tuberculosis and pneumonia.

The device and associated technologies are still under development (see Fig.29).

Dynamic Biomarkers also developed a device for the Qualcomm Tricorder



Fig,34: enlargement of the internal electronics of UV Sense.

Fig.35: the Nima peanut testing device. Results can be uploaded to a database so other users can see what products contain peanuts or what establishments have peanuts in their menu items. There is also a similar device to determine if products are gluten-free or not.

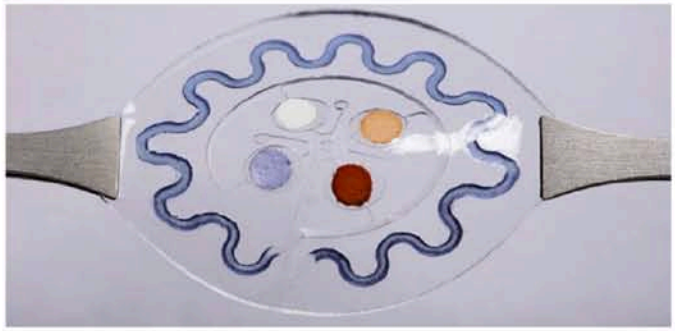


Fig.36: a sweat analysis patch before being fitted, with the various sensors and antenna clearly visible.

Fig.37: the sweat analysis patch sensors use the principles of microfluidics, ie, fluids moving through extremely small channels.

X-Prize, winning second place. It comprises a smartphone, vitals signs monitoring set, a scope set and gives the ability to perform blood, urine and breath tests (see Fig.30).

Vital signs that can be monitored include temperature, heart rate, blood pressure, respiration, and oxygen saturation. Signal processing techniques are also used to assess the risk for conditions such as atrial fibrillation and sleep apnoea.

It also includes a Bluetooth-enabled magnifying camera, to obtain high-resolution images of the skin and ear membrane.

Machine learning is used to analyse acquired images and calculate the risk for either melanoma or otitis media (middle ear infection). Extra computing power beyond what can be provided by the smartphone comes from cloud computing.

Blood, urine and breath tests are employed to analyse fluids or breath dynamics to diagnose conditions such as urinary tract infection, diabetes and chronic obstructive pulmonary disease.

Work is underway to develop a next-generation version of this device for use in developing countries.

For more information, see the video titled *"Final Frontier - Qualcomm Tricorder XPRIZE"* at: **siliconchip.com.au/link/aan0**

Monitoring UV light exposure

Overexposure to UV light causes sunburn and can increase the risk of skin cancer, which is a serious public health problem in Australia. "My UV Patch" is a product from La Roche-Posay which is intended to help users avoid this.

It is a wearable, flexible, stretchable, extremely thin (50 microns) adhesive patch that is applied to the skin (see Figs.31 & 32).

It contains a number of coloured squares with UV sensitive dyes that change colour with UV exposure. It also has some fixed reference colours. It also contains some flexible electronics that are 15 microns thick.

The electronics communicate with the smartphone via NFC (Near Field Communication) and convey an ID which is unique to the patch.

A smartphone app images the patch with its camera and the colour changes in the UV-sensitive dyes are used to determine personal UV exposure. The app takes into account the user's geographic location too, determined via GPS. The disposable patch can be worn for up to five days.

L'Oréal has also developed smartphone-connected UV monitoring products to enable improved skin care. They allow the user to measuring their exposure to harmful UV, enabling them to reduce it if exposure is excessive. They have produced two devices.

My Skin Track (**siliconchip.com.au/link/aan1**) is available now, in the form of a wearable sensor that can be hung around the neck or attached to clothing. It is waterproof and requires no batteries. A LED is used to sense UV light and it too communicates with a smartphone app via NFC (Near Field Communications).

The app also displays environmental data downloaded from the internet such as pollen count, pollution and weather. It indicates the proportion of maximum allowable UV exposure that has been reached according to a user's skin type.

UV Sense is a solar-powered device which attaches to

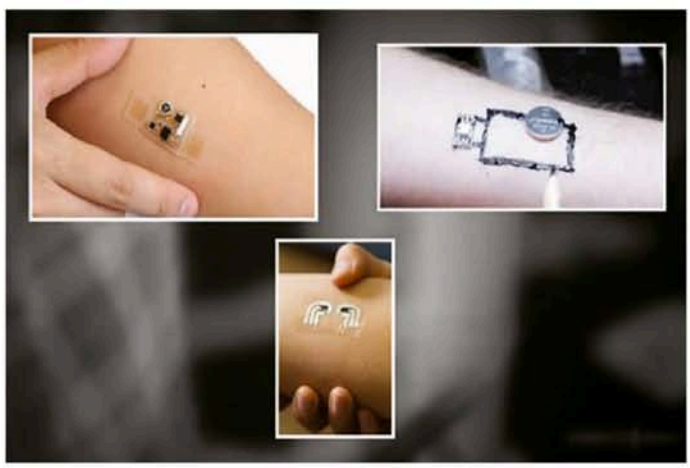


Fig.38: various "Tech Tats" by Chaotic Moon Studios.

Fig.39: the miCARE App, (still under development) monitors risk factors during pregnancy.

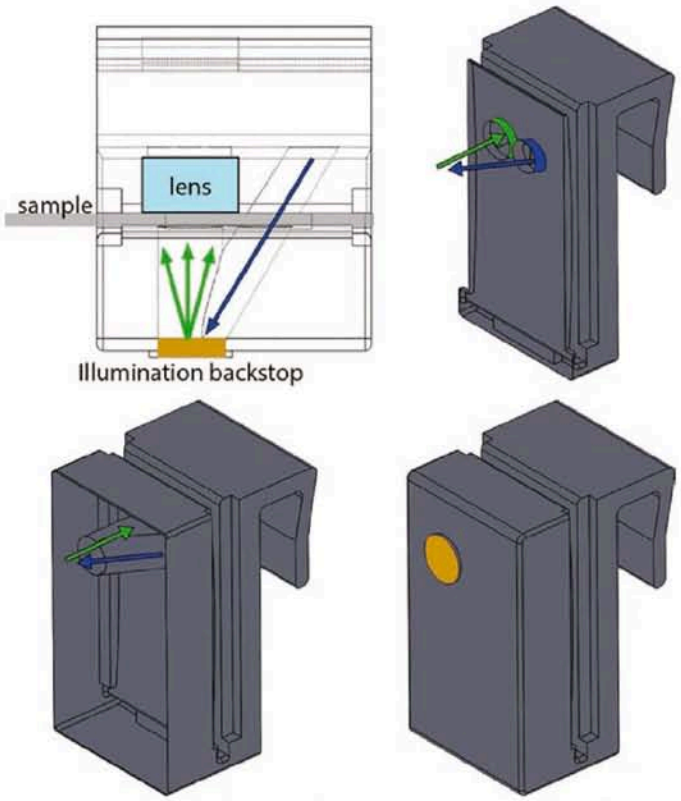


Fig.40: a 3D printed smartphone microscope. Either the smartphone flash or sunlight is used for illumination. Free 3D printer files are available to make this device yourself. All that is required apart from the 3D print is a cheap lens. ***Image source: https://doi.org/10.1038/s41598-018-21543-2***

a thumbnail. It can store up to three months of UV exposure data. It can be worn for up to two weeks at a time, then reattached with additional adhesive (see Figs.33 & 34).

The device was developed in conjunction with MC10 Inc, a leading wearable technology company, and professor John Rogers at Northwestern University (Illinois, USA – www.northwestern.edu/) It will be released globally later this year.

Picking up food-based allergens

Nima (https://nimasensor.com/) have developed smartphone-connected devices that detect if food is gluten-free or whether it contains peanuts.

The devices work by using antibodies that react to the proteins in gluten or peanuts and this results in a change in the antibody properties, which is detected by the device and the results can be sent to a smartphone for display and logging (see Fig.35).

Sweat analysis

Scientists at Northwestern University have also developed a stretchable, disposable electronic patch that adheres to the skin and which changes colour when exposed to sweat, revealing various body parameters such as pH, glucose, chloride and lactate.

Electronics in the patch trigger a smartphone bought to close proximity, which takes a picture and uses the colour changes to determine the values of these biomarkers (see Figs.36 & 37).

Skin sensors

"Tech Tats" is a concept from Chaotic Moon Studios,

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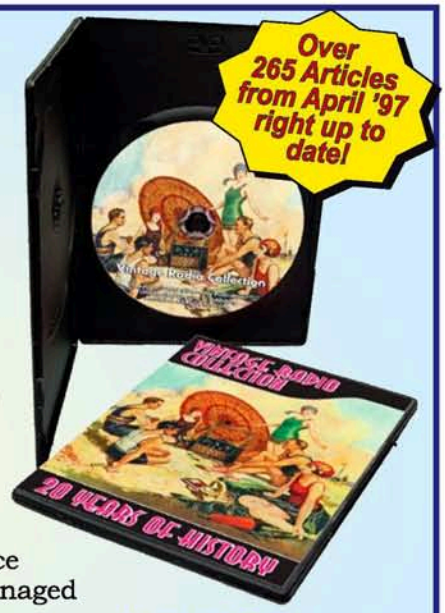

"Vintage Radio" is one of the most popular columns which appears every month in Australia's most-read and authoritative electronics magazine, SILICON CHIP.

Over the years many readers have asked us if there was a single source for all "Vintage Radio" articles so a particular set or sets they have managed to get hold of could be referenced. Until now, that was not possible.

But now it is!

We've put together a DVD# containing every "Vintage Radio" column for more than 20 years – from April 1997 right through to December 2018 – and included an easy-to-read index so you can find the one you're looking for. They're all provided in PDF format so the quality is even better than in the magazine (you can actually read many dials!). And there's much more than radios – there's articles on vintage TVs, amplifiers... all from a bygone era!

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Suffer from Gout? You should read this!

A number of Australian universities are currently calling for volunteers who suffer from gout AND own a smartphone with internet access to take part in the Australia-wide study of a new smartphone app to help manage and/or control their gout.

Gout is a form of inflammatory arthritis that develops in some people who have high levels of uric acid in the blood. The acid can form needle-like crystals in a joint and cause sudden, severe episodes of pain, tenderness, redness, warmth and swelling.

To take part in the study, you will:

- Use a mobile app for one year and record gout attacks;
- See your GP and have blood tests at least 3 times a year;
- Fill out 3 surveys, including questions about your gout and treatment.

You will be reimbursed for your time with a $30 gift voucher, after completing both a blood test and a survey at each time point of the study: the start, at 6 months, and 12 months ($90 in total).

If you know of anyone (including yourself!) who might be interested in participating, please feel free to share the study with them using the following link:

https://mygoutapp.com/

Texas, USA – (www.chaoticmoon.com) of electronics attached directly to the skin that can monitor various physiological parameters or carry data such as banking information or identity confirmation.

As you can see, they aren't really tattoos but look a bit like they are (see Fig.38).

For more information, see the video titled *"Chaotic Moon Studios - Tech Tats"* at: https://vimeo.com/144913588

Monitoring complicated pregnancies

There is a host of pregnancy-related apps available, in development or proposed – if you're interested, google "pregnancy apps" and you'll find them.

One which caught our eye is the UK-based miCARE, an app still under development but is designed to monitor various risk factors during pregnancy, such as detecting gestational diabetes.

The app monitors parameters such as blood glucose, blood pressure, weight and kidney function, however, it will not use specially designed peripherals to do this.

Rather, the app gets its data from existing equipment that is already in the at-risk pregnant mother's home (eg, via Bluetooth – see Fig.39).

Smartphone microscope for medical uses

Numerous smartphone microscopes have been developed over the years and they are all potentially suitable for medical applications such as the diagnosis of malaria, detection of E. coli or salmonella in food or assessment of water for parasites.

This would be especially useful in third-world countries which lack proper laboratory facilities. However, many smartphone microscopes have drawbacks such as bulkiness, the requirement of an external light source, difficulty in cleaning and the inability to view images in real time due to image processing overhead.

An Australian team at the ARC Centre for Nanoscale BioPhotonics (Macquarie University, Sydney) has overcome these disadvantages, creating an inexpensive 3D-printed design suitable for medical applications.

Fig.41: the mobile phone microscope by ARC Centre for Nanoscale BioPhotonics in use. Note the microscope slide in the first image. ***Image source: https://doi.org/10.1038/s41598-018-21543-2***

Specimens as small as 1/200th of a millimetre in diameter can be imaged, making it possible to view blood cells and cell nuclei among other things (see Figs.40 & 41).

The same Centre has also developed a bioassay device (see Fig.42).

If you have a 3D printer, you can actually make one of the ARC Centre-designed microscopes devices yourself. You can download the required files from http://cnbp.org.au/online-tools

All you need to add is a cheap lens from a mobile phone camera, which can be purchased online (or obtained from one of the estimated 23 million unused mobile phones hidden in drawers and cupboards at home . . .).

The future

The future for mobile-phone based medical devices is promising.

Ongoing miniaturisation will likely see these types of devices incorporated directly into smartphones of the future, which will enable them to become general-purpose medical monitoring devices.

That should lead to improved health outcomes and reduced health care costs SC

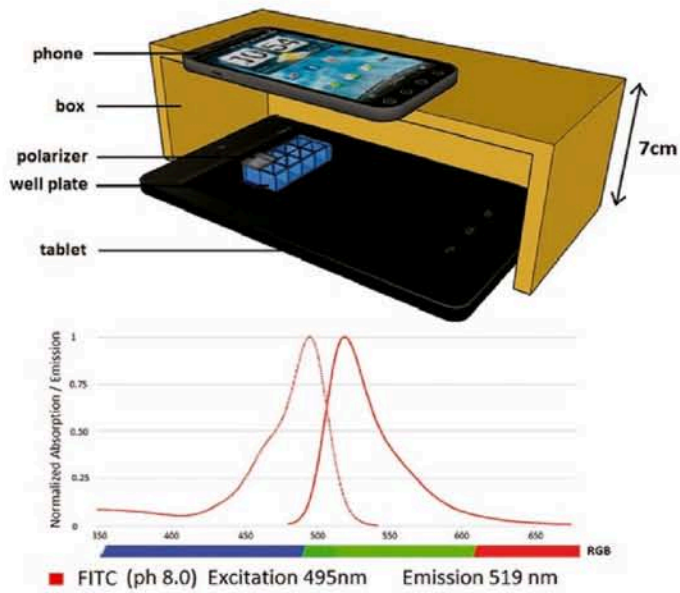

Fig.42: the smartphone bioassay device by ARC Centre of Excellence in Nanoscale Biophotonics. Certain colour channels of the smartphone camera are monitored to determine the amount of fluorescence from substances under test. ***Image source:*** ***https://doi.org/10.3390/s150511653***

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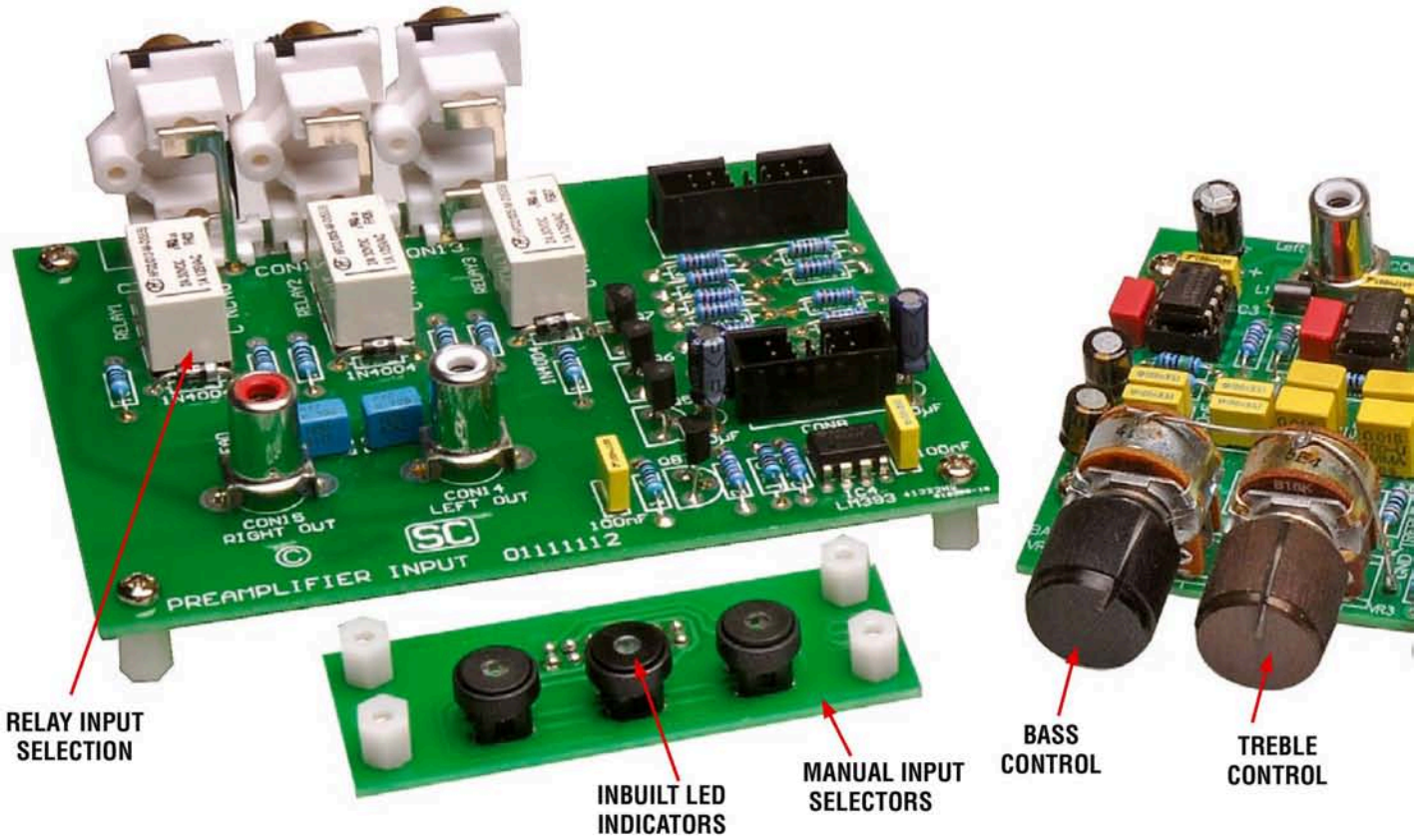


Ultra Low Distortion with Tone Controls

Many hundreds – perhaps thousands – of the Very Low Distortion Stereo Preamplifier we featured in November/December 2011 have been built. But there has been one continuing request: how do I add tone controls? Well, this new version not only *has* tone controls but with component improvement over the years, offers 25% improved performance. That alone makes it worth considering – but it also has infrared remote volume control, input switching and muting. Meet the 2019 Ultra Low Distortion Preamp!

Features:

- Very low noise and distortion
- Remote controlled input selection and volume control with muting
- Manual volume control plus bass and treble cut/boost controls
- Tone control defeat switch bypasses bass and treble controls
- Minimal interaction between tone controls
- Can be used with just about any power amplifier, including our Ultra-LD series and the 20W Class-A amp
- Designed to be mounted in the front of a stereo amplifier chassis, but is also suitable for standalone use
- Three status LEDs
- Runs from ±15V DC
- Similar size, shape and layout to our November/December 2011 Low Noise Preamplifier

Preamplifier

by John Clarke

This high-quality, low-distortion and low-noise stereo preamplifier can be used with just about any amplifier modules to form a stereo amplifier. It can also be used as a standalone preamp.

A low-cost infrared remote control is used to switch between three separate inputs, adjust the volume or temporarily mute the output.

It also includes manual volume, bass and treble controls and pushbuttons to select between the three stereo inputs.

LED indicators in the pushbuttons show which input is active. It also has power, acknowledge and mute status LEDs. All in all, it offers considerable advantages over previous models.

You could build it into an amplifier based on our Ultra-LD series of amplifier modules, such as the Ultra-LD Mk.4 (August-October 2015; www.siliconchip.com.au/Series/289).

Or you could use easy-to-build, low-cost SC200 amplifier modules (January-March 2017; siliconchip.com.au/Series/308; Altronics kit Cat K5157). Or build it in a case and use it with an existing power amp. It's up to you.

And since it has a motorised potentiometer for volume control, you can adjust the volume directly with a knob if you don't want to use the remote. It has an effectively-infinite number of possible volume settings, unlike most digital volume controls, which can have quite large steps.

This preamp has much better performance than most. While we have published a couple of very low noise and distortion preamps designs over the last decade or so, none of them had tone controls.

This one provides wide-range bass and treble adjustment knobs to allow you to overcome deficiencies in your loudspeakers, compensate for the room response or just adjust the sound to be the way you like it.

While the performance is excellent when the tone controls are active, we have provided the option to bypass them using a push on, push off switch. Its integrated LED indicator shows when the tone controls are switched in or out.

This switch has three benefits. One, it's difficult to centre the tone controls precisely when you want the response to be flat, so the switch provides an easy way to achieve that. Two, it provides slightly better performance with the tone controls switched out. And three, it gives you an easy way to hear exactly what effect the tone controls are having, by toggling them on and off.

A PIC microcontroller is used to provide the remote control, muting and input selection functions.

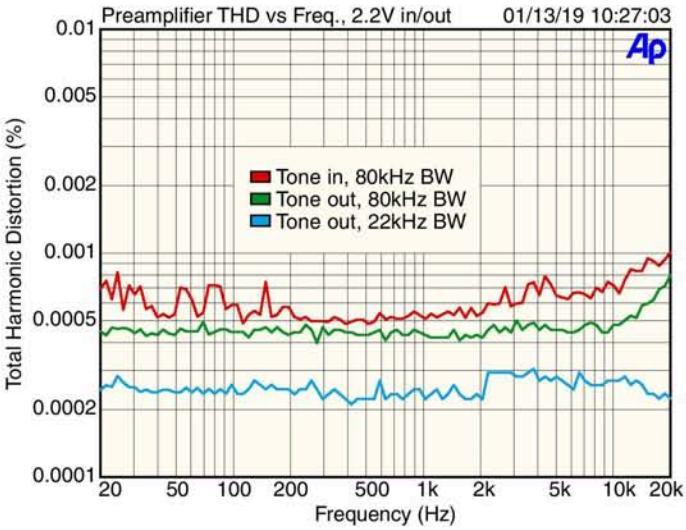


Fig.1: distortion across the entire range of audible frequencies is extremely low, whether the tone controls are active or not. There is a slight rise in distortion above 10kHz, but below that, the distortion is below the noise floor.

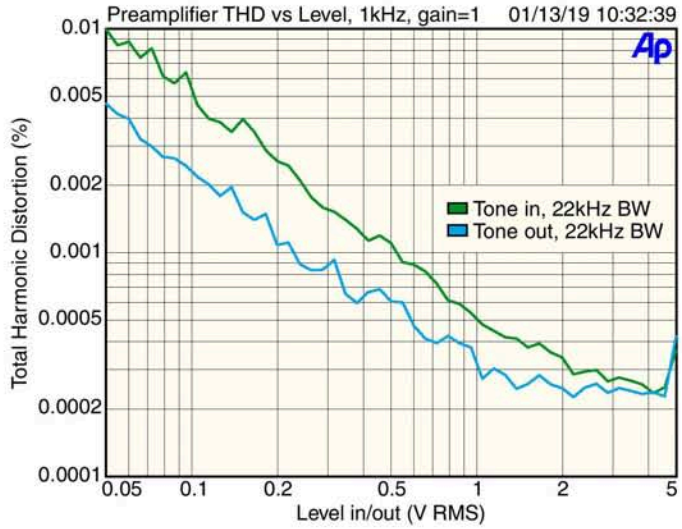


Fig.2: this shows the effect of noise; as you reduce the volume and thus the output signal level, the fixed circuit noise becomes larger in proportion and so total harmonic distortion goes up. However, even at very low volume levels, it's below 0.01% so it won't be noticeable.

Input selection is by way of a separate PCB interconnected to the main preamplifier using 10-way ribbon cable. If you don't need the input selector, you can build the project without it.

The micro remembers the last input selection, so it will go back to the same set of inputs even if it's switched off and on again.

Performance

This preamplifier has excellent performance. It uses low-distortion, low-noise op amps throughout, plus we have taken great care to specify very linear types of capacitor and to keep resistor values low, where their Johnson (thermal) noise contribution is likely to affect the signal.

Inevitably, the tone control circuitry adds some noise when it is switched in. But performance is still very good with the tone controls in, giving a THD+N figure of just 0.00054% at 1kHz and 0.0007% at 10kHz. By comparison, with the tone controls out, those figures become 0.00044% and 0.00048% respectively – see Fig.1.

Those measurements were made with a bandwidth of 20Hz-80kHz, which is necessary to measure distortion at higher frequencies accurately. But such a measurement includes a significant amount of ultrasonic noise (ie, in the 20-80kHz range). And Fig.1 shows that the distortion performance is dominated by noise.

So we also made measurements with a 20Hz-22kHz bandwidth, shown in blue on Fig.1, and this reveals that the true audible distortion and noise level is closer to 0.00025% – an astonishingly low figure.

Fig.3 shows the frequency response with the tone control at either extreme, and switched out (the blue curve). This demonstrates that when you're not using the tone controls, the frequency response is very flat. You can barely see the deviation on this plot; zooming in, we can see that the response is down only 0.2dB at 20Hz and less than 0.1dB at 20kHz.

Fig.4 shows the coupling between channels, which is typically less than -80dB, and the coupling between adjacent inputs, typically around -100dB. So isolation between channels and inputs is very good. The signal-to-noise ratio figure is especially good; over 120dB with a 2.2V RMS input signal (typical for CD/DVD/Blu-ray players), the tone controls switched out and the volume pot at unity gain.

In summary, you can be confident when using this preamp that it will not negatively affect the audio signals passing through it, regardless of whether you are using the tone controls.

Specifications *(2.2V RMS in/out, 20kHz bandwidth unless otherwise stated):*

Frequency response: .....flat from 20Hz to 20kHz (see Fig.3), -1.25dB @ 100kHz
Bass adjustment range:.....±15dB at 20Hz; ±13dB at 75Hz
Treble adjustment range:....±15dB at 20kHz; ±14dB at 10kHz
Input impedance: 22kΩ
Output impedance:.....100Ω
THD+N: .....<0.001%, 80kHz bandwidth;
.....typically <0.0003%, 20kHz bandwidth (see Fig.1)
Signal-to-noise ratio:.....-121dB with tone controls out; -114dB with tone controls in
Channel separation:.....>80dB @ 1kHz; >67dB @ 10kHz (see Fig.4)
Input separation:.....>98dB @ 1kHz; >80dB @ 10kHz
Maximum gain:.....two times (6dB)
Signal handling:.....up to 4V RMS input, 8V RMS output

Capacitor and potentiometer selection

We mentioned earlier that we're using linear capacitor types where that's important, and also keeping resistance values low to minimise thermal noise.

For capacitors between 10nF and 100nF, we have specified MKT polyester (plastic dielectric) types. While polyester is not quite as linear as polypropylene or polystyrene dielectrics, none of those capacitors are critical enough to cause a measurable increase in distortion, as demonstrated by our performance graphs.

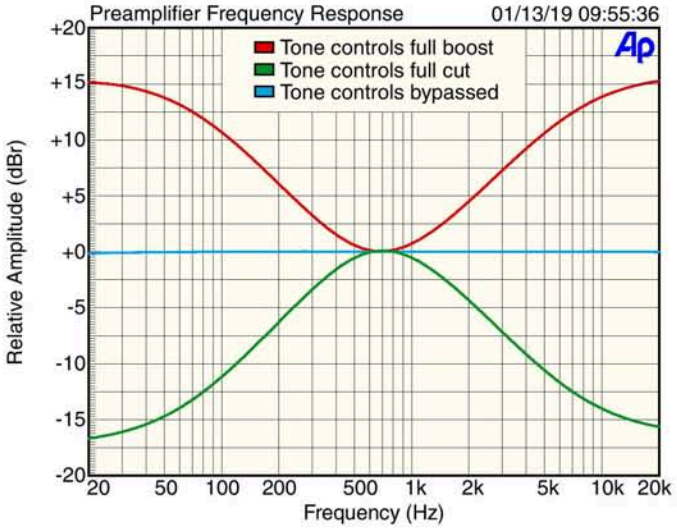


Fig.3: the blue line shows the preamp's frequency response with the tone controls switched out, and you can see that it's very flat, varying by only 0.2dB across the entire audible frequency range. The red and green curves demonstrate the range possible of bass and treble adjustments.

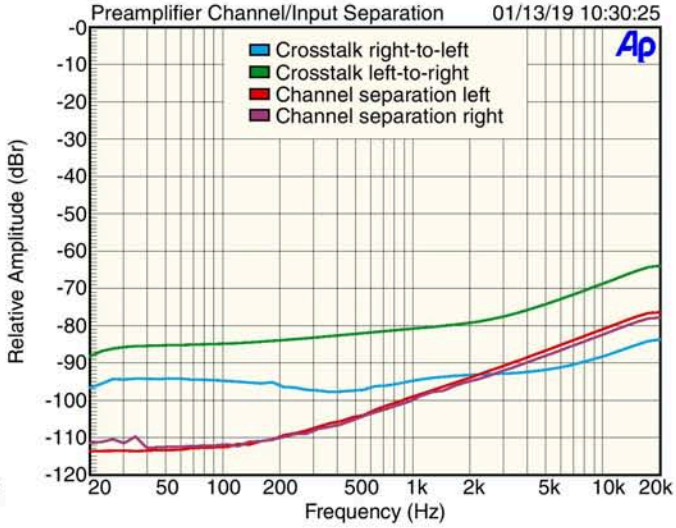


Fig.4: the crosstalk and separation figures are good. Crosstalk is how much of the left channel signal feeds into the right channel or vice versa. Channel separation is how much signal from input #1 couples into input #2 or vice versa.

But there are some capacitors with values below 1nF where the dielectric is important and this presents us with some difficulty, since MKT capacitors with values below 1nF are not particularly easy to get.

However, we've found them (see parts list) and that is what we have used in our prototype, with good result.

If you can get MKP (polypropylene) capacitors instead, those will certainly work well and we would encourage that. But we have also mentioned the possibility of using NP0 ceramics. We have tested these in the past and found that they are just as good as the best plastic dielectrics in situations where linearity is critical.

But be careful because many ceramic capacitors are not NP0 (also known as C0G) types, especially values above 100pF. Fig.5 shows a distortion plot for a simple low-pass filter comparing two capacitors of the same value, one polypropylene and one ceramic (not NP0/C0G). As you can see, the ceramic capacitor produces a lot more distortion. So make sure you use one of the types specified.

Regarding resistance, you may find it a bit strange that we have specified a 5kΩ volume control potentiometer as values in the range of 10kΩ-100kΩ are more commonly used. But we have chosen 5kΩ because the thermal noise contribution of the volume control pot can be a major limiting factor in the performance of a low-distortion preamplifier and suitable motorised pots are available.

Op amps IC1a & IC2a buffer the sig-

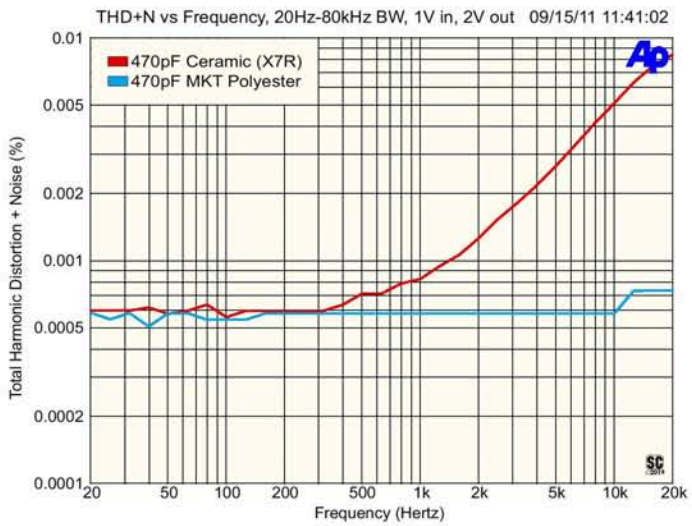


Fig.5: distortion versus frequency of a simple low-pass filter using either a 470pF MKT capacitor or a 470pF ceramic (non-NP0/C0G) capacitor. As you can see, distortion rises dramatically at higher frequencies with the ceramic capacitor due to its non-linearity and its lower impedance at higher frequencies, which causes it to shunt more of the signal and thus have a stronger effect.

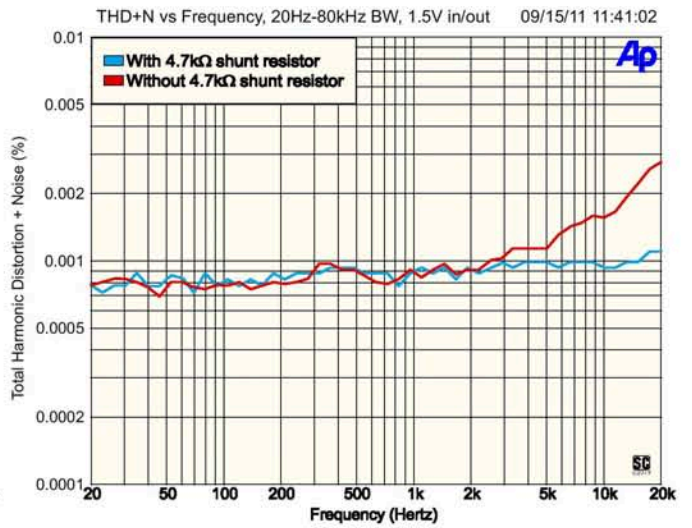
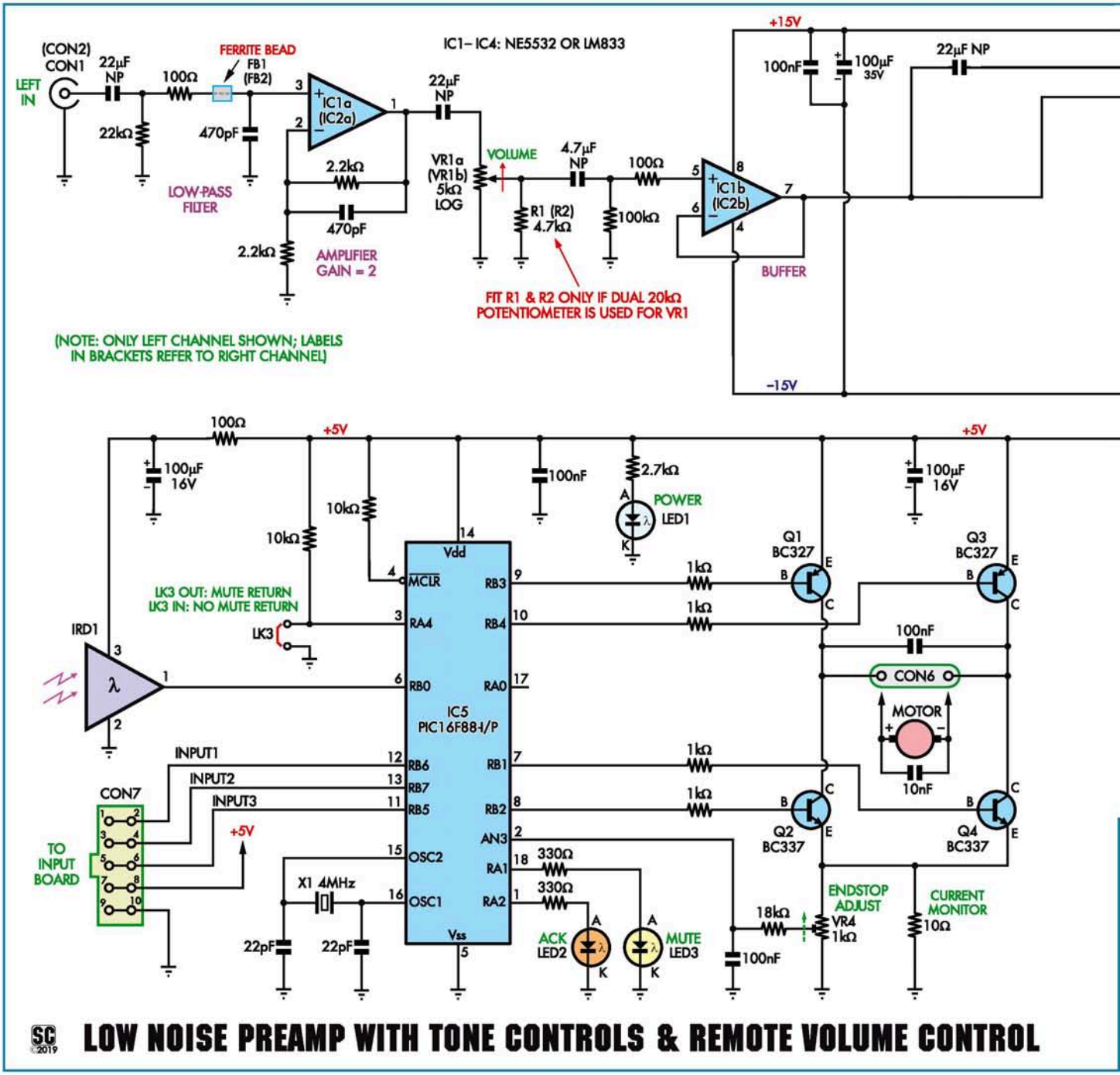


Fig.6: if you must use a 20kΩ motorised potentiometer to build this preamp, fitting the two extra 4.7kΩ resistors (R1 & R2) will keep high-frequency distortion low, by lowering the input impedance seen by the following buffer stage. This allows it to perform optimally and also lowers thermal noise.



LOW NOISE PREAMP WITH TONE CONTROLS & REMOTE VOLUME CONTROL

nal from the source so that it does not have to drive the 5kΩ impedance; the op amps are more than capable of driving such a load without increased distortion.

If you can't get the 5kΩ motorised pot (available from Altronics; see parts list), you can use a 20kΩ pot instead; also a pretty standard value.

In that case, we have made provision for two 4.7kΩ shunt resistors to lower the impedance seen by the following stage, giving you most of the performance benefits of a 5kΩ pot. These have minimal effect on the pot curve, so it still works well as a volume control.

Fig.6 shows the difference in distortion with and without these shunts (the signal level is lower here than in the other figures, hence the higher base level). The performance with the proper 5kΩ pot is slightly better again.

Remote control

Pressing the Volume Up or Volume Down buttons on the infrared remote causes the motorised pot to rotate clockwise or anticlockwise. It takes about nine seconds for the pot to travel from one end to the other using these controls.

For finer adjustment, the Channel Up and Channel Down buttons on the remote can be used instead. These cause the pot shaft to rotate about one degree each time one of these buttons is briefly pressed. Holding one of these buttons down rotates the pot from one end to the other in about 28 seconds.

If any of these buttons is held down when the pot reaches an end stop, a clutch in the motor's gearbox begins to slip so that no damage is done to the motor.

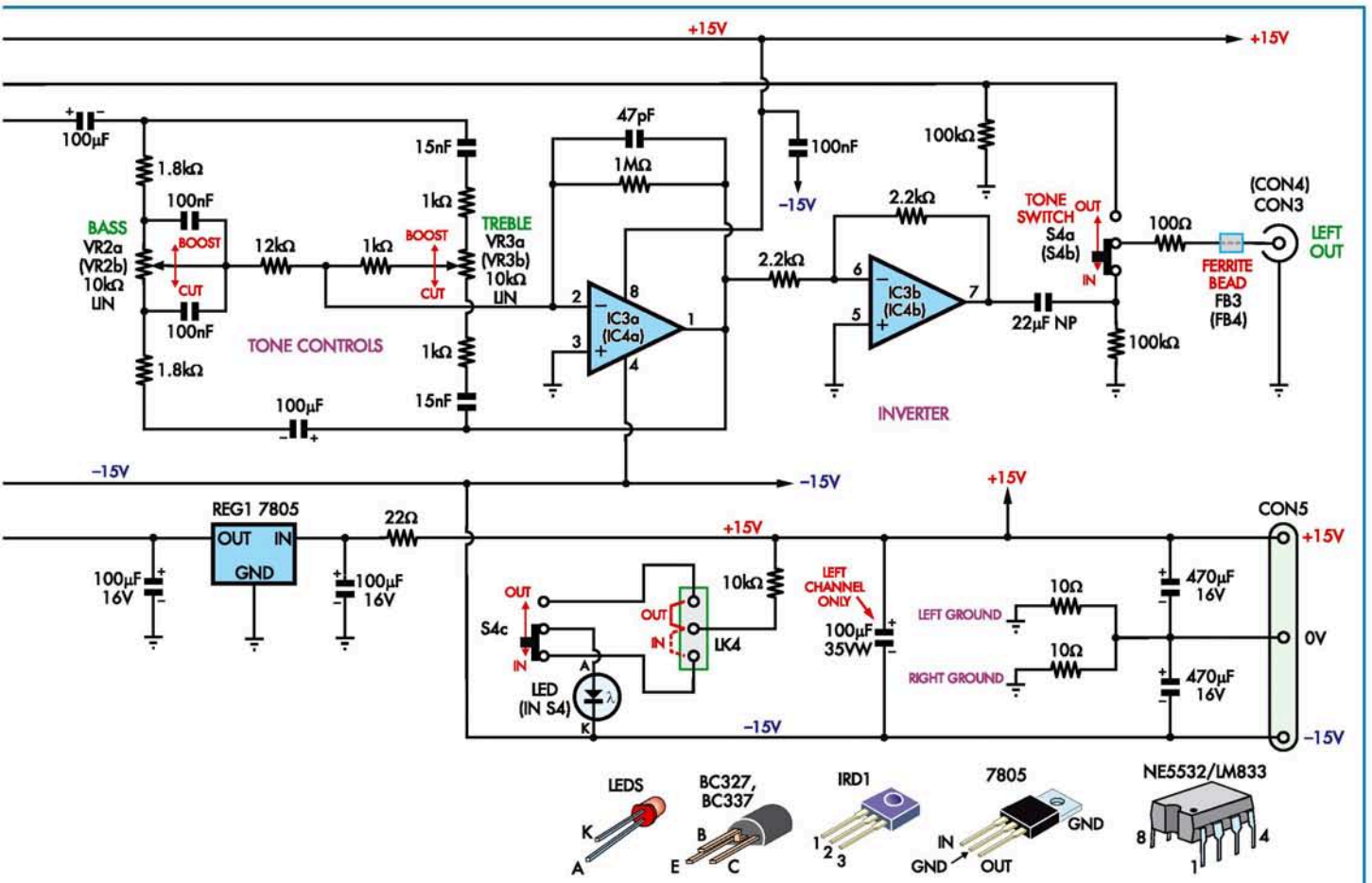


Fig.7: here's the circuit diagram for the main preamplifier PCB, incorporating the volume and tone controls and tone switching (at the top) and the infrared remote volume control and input switching circuitry (at bottom). The analog signal path is built around dual low-noise op amps IC1-IC4 and motorised potentiometer VR1. The volume control and input selection circuity is based on microcontroller IC5, motor driver transistors Q1-Q4 and infrared receiver IRD1.

The code also provides a convenient automatic muting feature. Press the Mute button on the remote and the volume control pot automatically rotates to its minimum position and the motor stops. Hit the button again and it returns to its original position. If you don't want the pot to return all the way to its original setting, you can simply increase the volume to your desired new level instead.

So how does the unit remember its original setting during muting? The answer is that the microcontroller monitors the time it takes for the pot to reach its minimum setting and the minimum pot setting is detected when the load on the motor increases at the potentiometer end stop, as the clutch begins to slip.

When the Mute button is pressed again, power is applied to the motor drive for the same amount of time, rotating it back to the original position.

The orange "Ack" LED flashes whenever an infrared signal is being received from the remote, while the yellow Mute LED flashes while the muting operation is in progress and then remains on when the pot reaches its minimum setting.

Circuit description

Fig.7 shows the main preamplifier circuit but only the left channel components are shown, for clarity. The right channel is identical and the matching part designators are provided, in brackets. The following description refers to the left-channel part names.

The audio signal from the Input Switching board is AC-coupled to the input of the first op amp (IC1a) via a 22µF non-polarised (NP) electrolytic capacitor and 100Ω resistor. A 22kΩ resistor to ground provides input DC biasing and sets the input impedance to around 22kΩ. The 100Ω resistor, ferrite bead and 470pF capacitor form a low-pass filter to attenuate radio frequency (RF) signals ahead of the op amp input.

IC1a operates as a voltage amplifier with a gain of two, due to the two 2.2kΩ feedback resistors. The 470pF capacitor combines with the feedback resistors to roll off the top-end frequency response, with a -3dB point at about 150kHz. This gives a flat response over the audio spectrum while eliminating the possibility of high-frequency instability or RF demodulation.

IC1a's pin 1 output is fed to the top of volume control potentiometer VR1a (5kΩ log) via a 22µF non-polarised capacitor. The signal on its wiper is then AC-coupled to the pin 5 non-inverting input of IC1b via a 4.7µF non-polarised capacitor.

This coupling arrangement prevents direct current from flowing through any part of the volume control potentiometer, VR1. Even a small direct current can cause noise when the volume is adjusted.

As mentioned earlier, the circuit was designed for a 5kΩ motorised volume

control pot as this results in good noise performance but in case you can't get one, you can use a more common 20kΩ potentiometer and fit resistors R1 and R2, so that the circuitry has a similar impedance, resulting in the same overall frequency response.

IC1b operates as a unity-gain buffer and provides a low-impedance output regardless of the volume control setting. Its pin 7 output is fed to the tone control section and also to switch S4a. When S4a is set to the 'tone out' position, the output from IC1b is coupled via the 22µF capacitor to output socket CON3, via a 100Ω resistor. Therefore, the tone controls are effectively out of circuit.

The 100Ω resistor isolates the op amp output from any capacitive loads that might be connected, to ensure stability. This resistor and ferrite bead in series with the output also attenuate any RF noise which may have been picked up by the board.

Tone controls

When S4a is in the 'tone in' position, output CON3 is instead driven from the tone control circuitry, so potentiometers VR2a and VR3a adjust the amount of bass and treble in the signal.

Op amp IC3a forms the active tone control in conjunction with VR2a and VR3a and associated resistors and capacitors. The bass and treble tone circuitry is a traditional Baxandall-style design. This is an inverting circuit, so it must be inverted again by unity gain buffer IC3b to restore the original signal phase.

When the wipers of potentiometers VR2a and VR3a are centred, the impedance between output pin 1 of IC3a and each wiper is equal to the impedance between the wiper and output pin 7 of IC1b. So in this condition, IC3a operates as a unity gain inverting amplifier for all audio frequencies. Therefore, in this case, the tone controls have little effect on the signal – they just add a little noise.

Bass adjustment

The bass control (VR2a) provides cut (anti-clockwise) or boost (clockwise) to low frequencies. The impedance of each of the two 100nF capacitors for high-frequency signals is low and so they can bypass VR2a entirely.

Any change in the position of VR2a's wiper will thus have little effect on high frequencies.

For example, at 1kHz, the 100nF capacitors have an impedance of 1.6kΩ each. That is considerably lower than the 5kΩ value of the half of the potentiometer track that they are connected across when VR2a is centred and therefore the capacitors shunt much of the signal around VR2a.

But at 20Hz, the 100nF capacitors have an impedance of 80kΩ and so minimal current passes through them; almost all of it goes through VR2a. Therefore VR2a has a significant effect on the amplitude of a 20Hz signal and so it provides much more boost or cut at lower frequencies.

When VR2a is rotated clockwise, the resistance from output pin 1 of IC3a to its wiper increases, while the resistance from the wiper to the input signal decreases, providing increased amplification. And when rotated anti-clockwise, the opposite occurs, decreasing amplification. Because the capacitors shunt a different amount of signal around the pot at different frequencies, this gain is also frequency-dependent.

The 1.8kΩ resistors set the maximum boost and cut range. They have been chosen to allow up to ±15dB adjustments at around 20Hz, dropping to around ±1dB at 1kHz. The measured frequency response with the controls at minimum, centred and at maximum is shown in Fig.3.

Treble adjustment

Treble control VR3a operates differently to VR2a. It is configured to have more effect on higher frequency signals. This is achieved by connecting capacitors in series with the pot channel, rather than across it.

At low frequencies, the 15nF capacitors have a high impedance, eg, 106kΩ at 100Hz. This is very high compared to the 10kΩ channel resistance and so most of the feedback signal at this frequency will flow through the bass network, which has a DC resistance of 13.6kΩ and therefore a much lower impedance. So VR3a will have little effect on the gain at low frequencies.

At high frequencies, the 15nF capacitors have a lower impedance, eg, around 1kΩ at 10kHz and so the treble controls are effectively brought into circuit, providing adjustable gain similarly to the circuitry surrounding VR2a. The 1kΩ resistors at each end of VR3a set the maximum boost or cut for high frequencies, up to around ±15dB, similar to the bass control. You can see this in Fig.3.

The 12kΩ and 1kΩ resistors between the bass and treble potentiometer wipers minimise the inevitable interaction between the two controls.

Note that while the treble potentiometer is isolated from direct current flow due to the 15nF capacitors in series, the bass potentiometer requires two extra 100µF capacitors. These do not affect the action of the bass control; they are just there to block direct current flow through VR2a. This is for the same reason that DC is blocked for VR1; to prevent noise during adjustments.

The 1MΩ feedback resistor between pins 1 and 2 of IC3a provides DC bias for the pin 2 input, while the 47pF capacitor prevents high-frequency oscillation of the op amp by reducing the gain at ultrasonic frequencies.

When S4a is set to the 'tone in' setting, the output from IC3b (reinverting IC3a's signal inversion) is then fed to the CON3 output as mentioned above. Another pole of the switch (S4c) controls the indicator LED that is contained within the switch. It is powered from the ±15V supplies via a 10kΩ resistor and therefore receives about 3mA.

Jumper link LK4 can be removed to prevent this LED from lighting, or moved into one position or the other to invert its function. In other words, LK4 selects whether the LED lights when the tone is in or out. Note that the 'tone out' position of S4 is when the switch is pressed in. In other words, it acts like a defeat switch.

Remote control circuitry

The Remote Control circuitry is also shown in Fig.7. Signals from the handheld remote are picked up by infrared receiver IRD1. This is a complete infrared detector and processor. It picks up the 38kHz pulsed infrared signal from the remote and amplifies it to a constant level. This is then fed to a 38kHz bandpass filter, after which it is demodulated to produce a serial data burst at its pin 1 output.

The resulting digital data then goes to the RB0 digital input (pin 6) of PIC16F88-I/P microcontroller IC5 for decoding. Depending on the button pressed on the remote, IC5 either drives the volume control motor (via an external transistor circuit) to change the volume, or sends one of its RB6, RB7 or RB5 output low to select a

A variety of infrared remote controls can be used to control the preamplifier: this one came from Altronics.

new input.

The input routing is controlled by the Input Selector board which is connected via CON7.

IC5 is programmed for a remote control which sends Philips RC5 codes. It supports three different sets of RC5 codes, normally referred to as TV, SAT1 or SAT2. You must also program the universal remote control with the correct number for one of these sets of code. We will explain how to do that next month. You also need to set IC5 to expect the correct set of codes; we will also describe that next month.

Driving the pot motor

IC5's RB1-RB4 outputs (pins 7-10) drive the bases of transistors Q1-Q4 via 1kΩ resistors. These transistors are arranged in an H-Bridge configuration and control the motor. The motor is off when the RB1-RB4 outputs are all high. In that state, RB3 and RB4 turn PNP transistors Q1 and Q3 off, while RB1 & RB2 turn NPN transistors Q2 and Q4 on.

As a result, both terminals of the motor are pulled low and so no current flows through it and it won't rotate.

The emitters of Q2 and Q4 both connect to ground via a common 10Ω resistor, which is used for motor current sensing. The transistors operate in pairs so that the motor can be driven in either direction to rotate the potentiometer either way, to increase or decrease the volume.

To drive the motor clockwise, RB2 goes low and turns off transistor Q2, while RB3 goes low and turns on Q1. When that happens, the left-hand terminal of the motor is pulled to +5V via Q1, while the right-hand terminal is pulled low via Q4. As a result, current flows through Q1, through the motor and then via Q4 and the 10Ω resistor to ground.

Conversely, to turn the motor in the other direction, Q1 and Q4 are switched off and Q2 and Q3 are switched on. As a result, the right-hand motor terminal is now pulled to +5V via Q3, while the left-hand terminal is pulled low via Q2.

Regardless of the direction of rotation, current flows through the 10Ω shared emitter resistor and so the voltage across it varies with the current drawn. Typically, the motor draws about 40mA when driving the potentiometer but this rises to over 50mA when the clutch is slipping. As a result, there is about 0.4-0.5V drop across the 10Ω resistor.

This is ideal because the motor is rated at 4.5V and the result of subtracting the resistor voltage from the 5V supply is that it provides the correct motor voltage.

Current sensing & muting

Once the potentiometer has reached full travel in either direction, a clutch in the motor's gearbox begins to slip. This prevents the motor from stalling and possibly overheating if the button on the remote continues to be held down. The clutch mechanism also allows the user to rotate the pot shaft manually.

As mentioned earlier, when you press the mute button on the remote control, the volume control is rotated fully anti-clockwise. Microcontroller IC5 detects when the wiper reaches its end stop by detecting the increase in the motor current when the limit is reached and the clutch slips. That's done by taking a sample portion of the voltage across the 10Ω resistor using trimpot VR4.

The voltage at VR4's wiper is filtered using an 18kΩ resistor and a 100nF capacitor to remove the motor commutator hash and is applied to lC5's analog AN3 input (pin 2). IC3 then measures the voltage on AN3 to a resolution of 10 bits, or about 5mV ($5V \div 2^{10}$).

Provided this input is below 200mV, the PIC microcontroller allows the motor to run. However, as soon as the voltage rises above this 200mV limit, the motor is stopped. When the motor is running normally, the current through it is about 40mA, which produces 0.4V across the 10Ω resistor. VR4 attenuates this voltage and is adjusted so that the voltage at AN3 is slightly below the 200mV limit.

Note that the AN3 input is monitored only during the muting operation. At other times, when the volume is being set by the Up or Down buttons on the remote, the clutch in the motor's gearbox assembly slips when the potentiometer reaches its clockwise or anticlockwise limits.

As described previously, pressing the Mute button on the remote again after muting returns the volume control to its original setting, by driving it clockwise for the same amount of time that it was driven anti-clockwise to reach its end stop.

This mute return feature in the software is enabled by leaving shorting link LK3 open. This allows the RA4 input (pin 3) to be pulled to 5V by a 10kΩ resistor. Installing the jumper shunt at LK3 will pull RA4 to ground, disabling the mute return feature.

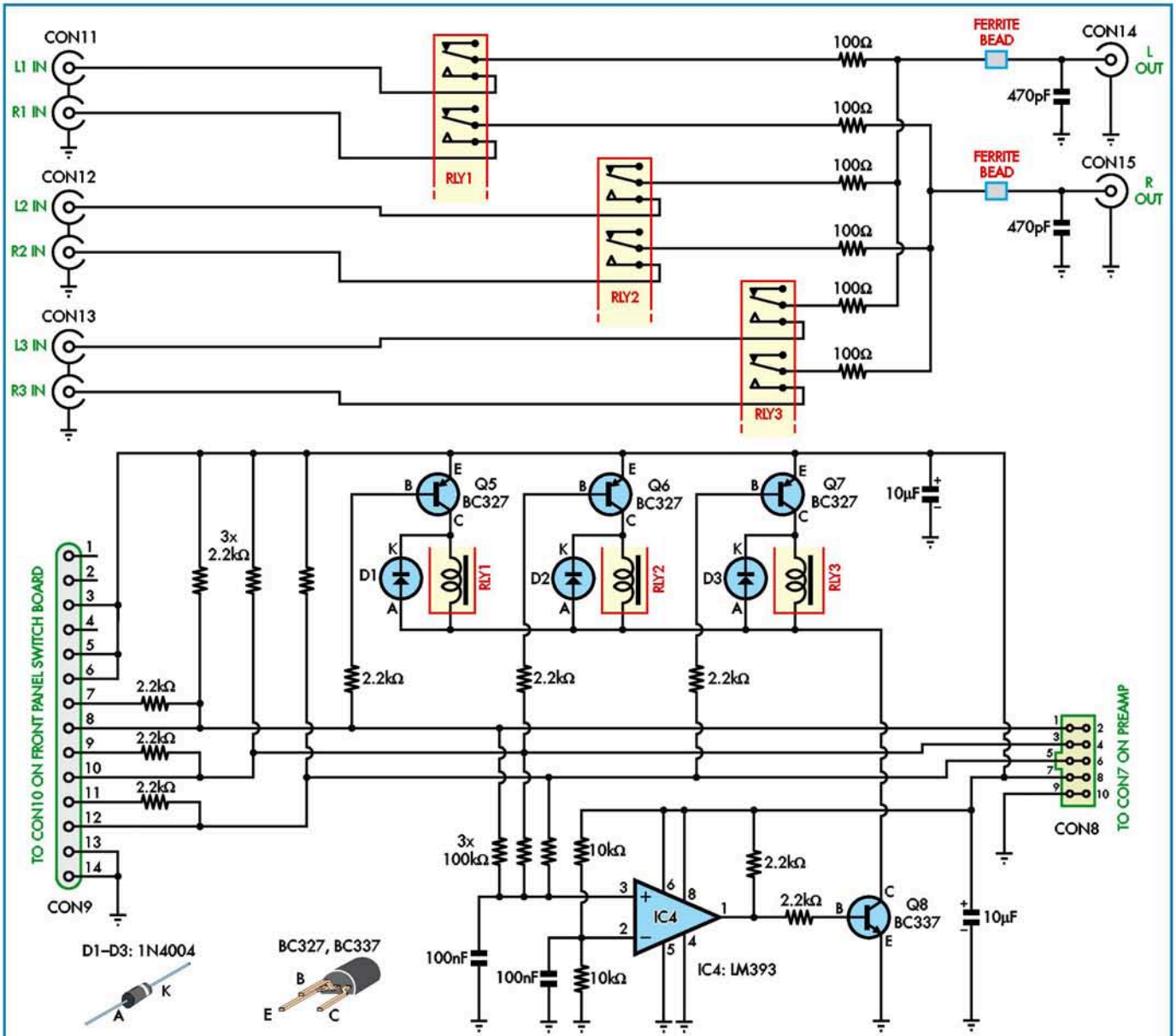
Status LEDs

LEDs1-3 indicate the status of the circuit. The blue Power LED (LED1) lights whenever power is applied to the circuit. The other two LEDs, Acknowledge (LED2) and Mute (LED3) light when their respective RA2 and RA1 outputs are driven high (ie, to +5V). LED2 indicates that an infrared command was received and LED3 lights when the mute function is active.

Pins 15 & 16 of IC5 connect to the oscillator which drive 4MHz crystal X1, providing the microcontroller system clock. This oscillator runs when the circuit is first powered up for about 1.5 seconds. It also runs whenever an infrared signal is received at RB0 or when a button on the front panel switch board is pressed and then for a further 1.5 seconds after the signal ceases.

The oscillator then shuts down and the processor goes into sleep mode, as long as a muting operation is not in process. This ensures that no noise is radiated into the sensitive audio circuitry when the remote control circuit is not being used.

A 10nF capacitor connected directly across the motor terminals also prevents commutator hash from being transmitted along the supply leads, while further filtering is provided by a 100nF capacitor located at the motor output terminals on the PCB. This



ULTRA LOW NOISE PREAMPLIFIER INPUT SELECTOR

Fig.8: the circuitry of the optional module used for input switching. One of DPDT relays RLY1-RLY3 is energised at any given time, feeding one of the input pairs (CON11-CON13) through to CON14/CON15, which are wired to inputs CON1 and CON3 on the main preamp board. IC4 and Q8 ensure that only one relay can be energised at a time, so the signal sources are not shorted to each other.

reduces the amount of noise that gets into the preamplifier signals when the volume pot motor is being driven.

Input selection

Digital outputs RB6, RB7 and RB5 of IC5 (pins 11-13) control the relays on the Input Selector Board. These outputs go low when the 1, 2 or 3 buttons on the remote are pressed respectively; they are high-impedance (set as inputs) the rest of the time. As shown, RB6, RB7 and RB5 are connected to pins 1-6 of 10-way header socket CON7; each output is connected to two pins in parallel.

Pins 7 and 8 of CON7 are wired to the +5V rail while pins 9 and 10 go to ground. CON7 is connected to a matching header socket on the Input Selector Board via an IDC cable. This provides both the control signals and the supply rails to power this module.

The Input Selector circuit is shown in Fig.8. It uses three 5V DPDT relays (RLY1- RLY3) to select one of three stereo inputs: Input 1, Input 2 or Input 3. The relays are driven by PNP transistors Q5-Q7, depending on the signals from the IC5 microcontroller in the Remote Control circuit (and fed through from CON7 to CON8).

One relay is used per stereo input so that the audio signal only has to pass through one relay. As shown, the incoming stereo line-level inputs are connected to the NO (normally open) contacts of each relay. When a relay turns on, its common (C) contacts connect to its NO contacts and the stereo signals are fed through to the left and right outputs via 100Ω resistors and ferrite beads.

The resistors isolate the outputs from the audio cable capacitance, while the beads and their associated 470pF ca-

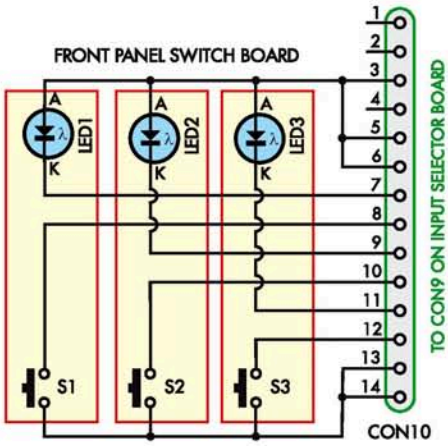


Fig.9: the circuitry on the front panel pushbutton switch board. LEDs 1-3 are actually inside the pushbutton switches and light when the corresponding input is selected

pacitors filter any RF signals that may be present.

When button 1 is pressed on the remote, pins 1 and 2 on CON8 are pulled low (by output RB6 of IC5 in the Remote Control circuit). This pulls the base of transistor Q5 low via a 2.2kΩ resistor and so Q5 turns on and switches on RLY1 to select input 1 (CON11). Similarly, RLY2 & RLY3 are switched on via Q6 & Q7 respectively when buttons 2 and 3 are pressed on the remote.

Only one relay can be on at any time. Pressing an input button (either on the remote or the switch board) switches the currently activated relay off before the newly selected relay turns on. If the input button corresponds to the currently selected input, then no change takes place. The last input selected is restored at power up.

Fig.9 shows the circuitry for the separate front panel Pushbutton Switch Board. This consists of three momentary contact pushbuttons with integral blue LEDs (LEDs1-3) plus a 14-way header socket (CON10) which is connected to CON9 via an IDC cable.

One side of each switch is connected to ground, while the other connections to S1-S3 are respectively connected back to the RB6, RB7 & RB5 digital I/Os of IC5 in the Remote Control circuit.

When a switch is pressed, it pulls its corresponding pin low and this wakes the microcontroller up, which then turns on the corresponding relay and promptly goes back to sleep again. The anodes of LEDs1-3 are connected to +5V, while their cathodes are respectively connected to the RB6, RB7 & RB5 I/Os of IC5 (pins 11-13) via 2.2kΩ current limiting resistors.

As a result, when one of these pins goes low to select a new input, it lights the corresponding switch LED as well. This occurs whether the input was selected using the remote control or pressing a switch button. The cathodes of the other LEDs are held high via 2.2kΩ pull-up resistors to the +5V rail and are off.

Note that the pins which are used to sense when buttons are pressed and drive the switch LEDs are the same pins which are used to drive the transistors which drive the relay coils.

So if you press the button corresponding to the input which is already selected, that line is configured as an output but it's already low (at ground potential), so pressing the button has no effect.

If you press one of the other buttons, as mentioned earlier, that pin on IC5 has been configured as an input and there are 2.2kΩ pull-up resistors on the Input Selector board. So pulling that line to ground will bring that line low, signalling to the microcontroller that you wish to switch inputs, which will then switch off the relay selecting the currently active input.

Preventing switch conflicts

Comparator IC4 and NPN transistor Q8 prevent more than one relay from switching on if two or more input switches are pressed simultaneously. This circuit also ensures that the currently activated relay is switched off if a different input button is pressed, before the newly selected relay is switched on.

IC4 is an LM393 which is wired so that its non-inverting input (pin 3) monitors the three switch lines via 100kΩ resistors.

These resistors function as a simple DAC (digital-to-analog converter). If one switch line is low, the voltage on pin 3 of IC1 is 3.3V; if two are low (eg, if two switches are pressed simultaneously), pin 3 is at 1.67V; and if all three lines are low, pin 3 is at 0V.

This pin 3 voltage is compared to a 2.5V reference on IC1's inverting input (pin 2), formed by a resistive divider across the 5V supply. So its pin 1 output is high only when one switch line is low and this turnss on Q8 which connects the bottom of the relay coils to ground. This allows the selected relay to turn on.

However, if two or more switch lines are low, IC4's output will be low and so Q8 and all the relays turn off. Similarly, if one switch line is already low and another input is selected (pulling its line low), IC4's output will briefly go low to switch off all the relays before going high again (ie, when the micro changes the state of its RB5-RB7 outputs) to allow the new relay to turn on.

Power supply

The Preamplifier is powered from ±15V rails. These are typically derived either from two separate 15V windings on the main power transformer, or a small secondary 15-0-15 transformer and rectifier.

Our Ultra-LD power supply board, (0119111) described in the September 2011 issue, is suitable for use with a wide range of audio amplifiers but more importantly for this project, provide regulated +15V and -15V outputs.

These 15V rails are bypassed on the preamp board by 470µF capacitors. There are other capacitors connected across the supply rails at various points of the circuit which provide local bypassing for the op amps on the PCB.

We use both 100nF capacitors and 100µF capacitors to ensure low impedance at a range of frequencies. The capacitors connected across the full 30V supply are rated at 35V or more.

The 5V supply for microcontroller IC5 is derived from the +15V rail via a 22Ω dropping resistor and 5V linear regulator REG1. The 22Ω resistor reduces the dissipation in REG1 and provides some additional filtering, in combination with REG1's 100µF input capacitor. The power LED, LED1, lights up when 5V is present and its current is set by a 2.7kΩ series resistor.

If you aren't using our Ultra-LD Amplifier power supply board, or another board which provides the required ±15V rails, don't worry. It's quite easy to build a suitable regulated supply.

We published a suitable design the in the March 2011 issue, titled "Universal Voltage Regulator" (siliconchip.com.au/Article/930) which is available as a Jaycar kit (Cat KC5463).

Our May 2015 4-Output Universal Voltage Regulator can also be used. It has adjustable outputs which can be set for ±15V, plus 5V and 3.3V outputs that could be used to power other circuitry in your preamp/amplifier.

All the PCBs mentioned available from the Silicon Chip Online Shop and the other parts required are easy

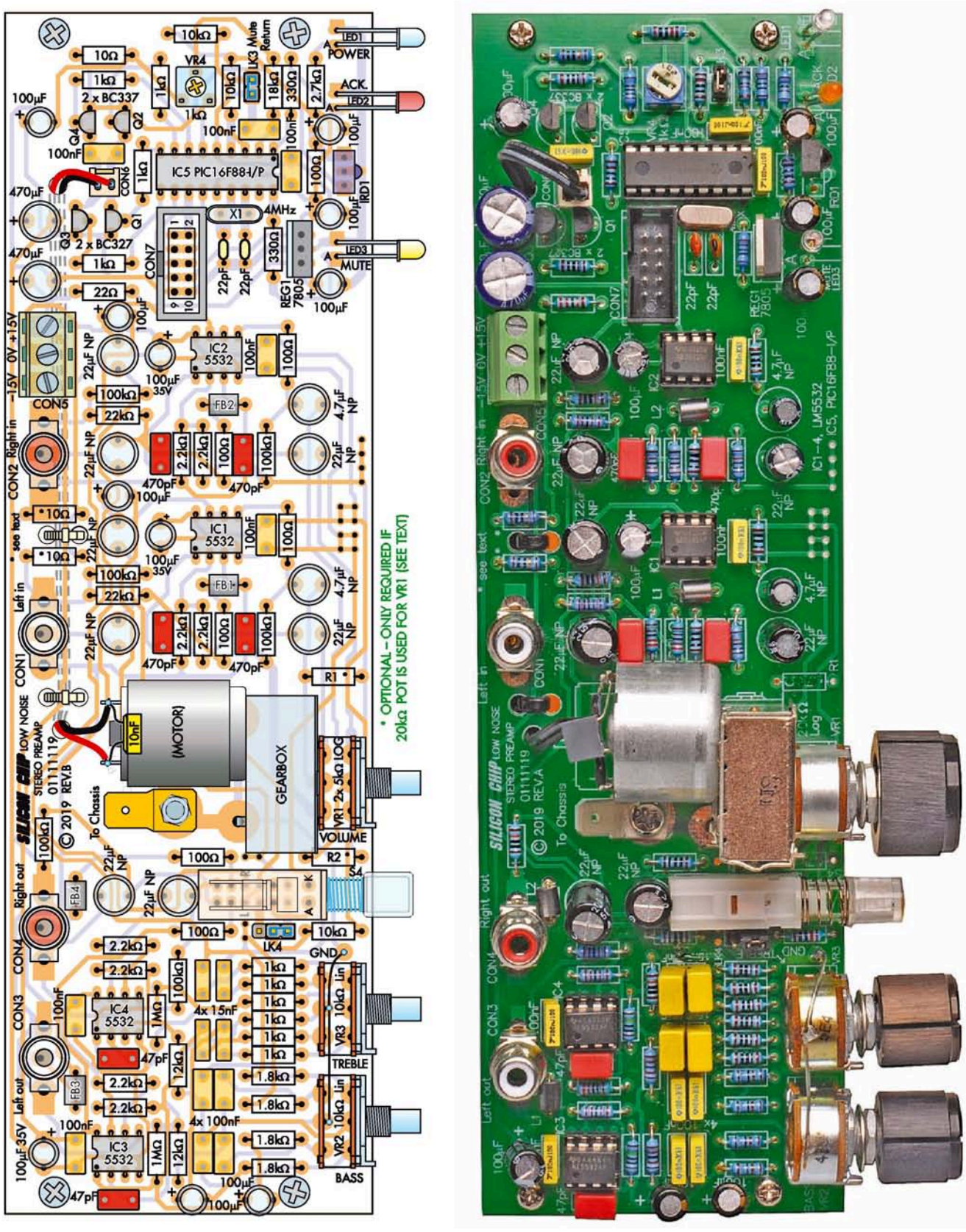


Fig.10: use this PCB overlay diagram as a guide when building the main preamp board. Don't forget to cut the pot shafts to length before soldering them. You will also need to remove some of the passivation layer from the top of VR2 and VR3 to allow you to solder the GND wire to Earth the pot bodies. Bend the leads of LED1-LED3 and IRD1 to suit your case, so that the LEDs protrude through the front of the case. You can make a hole for infrared light to reach IRD1 at the same level and cover it with a small piece of perspex to prevent dust ingress. See the parts list for details on the red capacitors.

Parts list – 2019 Ultra Low Distortion Preamplifier with Tone Controls

Main module

1 double-sided PCB, code 01111119, 216 x 66mm
1 universal remote control [Altronics A1012 or similar]
1 dual-gang 5kΩ log motorised potentiometer (VR1) [Altronics R1998] (a 20kΩ log pot can be substituted)
2 dual-gang 10kΩ linear 16mm potentiometers (VR2,VR3) [Altronics R2296]
1 1kΩ mini horizontal trimpot (VR4)
3 knobs to suit VR1-VR3
1 4PDT push-on, push-off switch (S4) [Altronics S1451]
4 8-pin DIL IC sockets (for IC1-IC4)
1 18-pin DIL IC socket (for IC5)
4 ferrite beads (FB1-FB4) [Altronics L5250A, Jaycar LF-1250]
1 4MHz crystal (X1)
2 vertical PCB-mount RCA sockets, white (CON1,CON3) [Altronics P0131]
2 vertical PCB-mount RCA sockets, red (CON2,CON4) [Altronics P0132]
1 3-way PCB-mount terminal block, 5.08mm pitch (CON5)
1 2-way vertical polarised header, 2.54mm pitch (CON6) [Altronics P5492, Jaycar HM-3412]
1 2-way polarised header plug (for CON6) [Jaycar HM-3402, Altronics P5472 & P5470A]
1 10-pin PCB-mount IDC vertical box header (CON7) [Altronics P5010, Jaycar PP-1100]
1 2-way SIL pin header (LK3)
1 3-way SIL pin header (LK4)
2 jumper shunts (LK3,LK4)
1 6.35mm chassis-mount single spade connector
4 12mm long M3 tapped Nylon spacers
1 M4 x 10mm panhead machine screw
1 M4 hex nut
1 M4 star washer
4 M3 x 6mm panhead machine screws
2 100mm cable ties
1 150mm length of light-duty figure-8 hookup wire
1 50mm length of 0.7mm diameter tinned copper wire
1 PC stake

Semiconductors

4 NE5532AP or LM833P dual op amps (IC1-IC4)
1 PIC16F88-I/P microcontroller programmed with 0111111A.hex (IC5)
1 infrared receiver module (IRD1) [Altronics Z1611A, Jaycar ZD1952]
1 7805CV 5V regulator (REG1)
2 BC327 PNP transistors (Q1,Q3)
2 BC337 NPN transistors (Q2,Q4)
1 3mm blue LED (LED1)
1 3mm orange/amber LED (LED2)
1 3mm yellow LED (LED3)

Interconnecting cables

1 350mm length of 14-way IDC cable
1 250mm length of 10-way IDC cable
2 10-pin IDC line sockets [Altronics P5310]
2 14-pin IDC line sockets [Altronics P5314]

Capacitors

2 470µF 16V PC electrolytic
3 100µF 35V PC electrolytic
8 100µF 16V PC electrolytic
8 22µF small non-polarised electrolytic
2 4.7µF small non-polarised electrolytic
11 100nF MKT polyester
4 15nF MKT polyester
1 10nF MKT polyester
4 470pF MKT polyester, MKP polypropylene or NP0 ceramic [eg, element14 1005988]
2 47pF MKT polyester, MKP polypropylene or NP0 ceramic [eg, element14 1519289]
2 22pF ceramic

Resistors (all 0.25W, 1% metal film)

2 1MΩ	6 100kΩ	2 22kΩ	1 18kΩ	2 12kΩ
3 10kΩ	1 2.7kΩ	8 2.2kΩ	4 1.8kΩ	10 1kΩ
2 330Ω	7 100Ω	1 22Ω	3 10Ω	

Input Switching module

1 PCB, code 01111112, 109.5 x94.5mm
3 DPDT 5V relays, PCB-mount (RLY1-RLY3) [Altronics S4147]
3 PCB-mount vertical stacked dual RCA sockets (CON11-CON13) [Altronics P0212]
1 vertical PCB-mount RCA socket, white (CON14) [Altronics P0131]
1 vertical PCB-mount RCA socket, red (CON15) [Altronics P0132]
1 10-pin PCB-mount IDC vertical box header (CON8) [Altronics P5010, Jaycar PP1100]
1 14-pin PCB-mount IDC vertical box header (CON9) [Altronics P5014]
2 ferrite beads [Altronics L5250A, Jaycar LF1250]
4 12mm long M3 tapped Nylon spacers
4 M3 x 6mm panhead machine screws

Semiconductors

1 LM393P comparator (IC4)
3 BC327 PNP transistors (Q5-Q7)
1 BC337 NPN transistor (Q8)
3 1N4004 diodes (D1-D3)

Capacitors

2 10µF 16V electrolytic
2 100nF MKT polyester
2 470pF MKT polyester, MKP polypropylene or NP0 ceramic [eg, element14 1005988]

Resistors (all 0.25W, 1% metal film)

3 100kΩ	2 10kΩ	11 2.2kΩ	6 100Ω

Front Panel Pushbutton module

1 PCB, code 01111113, 66 x 24.5m
1 14-pin PCB-mount IDC vertical box header (CON10) [Altronics P5014
3 PCB-mount pushbutton switches with blue LEDs (S1-S3) [Altronics S1173, Jaycar SP0622]
4 6.3mm long M3 tapped Nylon spacer
4 M3 x 6mm panhead machine screws

to obtain from your favourite electronics retailer.

Construction

Fig.10 shows the assembly details for the main Preamplifier module. It is built on a PCB coded 01111119 which measures 216 x 66mm.

Begin by installing the resistors (use your DMM to check the values), followed by the four ferrite beads. Each bead is installed by feeding a resistor lead off-cut through it and then bending the leads to fit through their holes in the PCB. Push each bead all the way down so that it sits flush against the PCB before soldering its leads.

Following this, install the IC sockets for the five ICs. Make sure that each socket is seated flush against the PCB and that it is orientated correctly, as shown in Fig.10. Note that IC5 faces in the opposite direction to the op amp ICs (IC1-IC4). It's best to solder two diagonally opposite pins of a socket first and then check that it sits flush with the board before soldering the remaining pins.

The MKT and ceramic capacitors can now go in, followed by the electrolytic capacitors (regular and non-polarised). The electrolytic capacitors must be oriented with the correct polarity, ie, with the longer lead through the pad marked with a "+" symbol. The 100µF capacitors that are marked on the overlay and PCB with 35V must be rated at 35V or higher.

If you use ceramic 470pF or 47pF capacitors, make sure they are the specified NP0 (or the equivalent C0G) type. Using other types of ceramic capacitors in these positions will degrade the distortion performance.

The next step is to install the four transistors (Q1-Q4) in the remote control section. Be sure to use the correct type at each location. Q1 and Q3 are both BC327s, while Q2 and Q4 are BC337s.

The PC stake (near VR3), 2-way SIL pin header for LK3 and 3-way SIL header for LK4 can now be installed, followed by polarised pin header CON6 and box header CON7. Crystal X1, trimpot VR4, the 3-way screw terminal block (CON5) and the four vertical RCA sockets (CON1-CON4) can then be fitted.

Ensure the terminal block wire entry holes face the nearest edge of the PCB. Use white RCA sockets for the left channel input and output positions and red for the right channel positions.

Switch S4 can be mounted now. Take care that all the pins are straight before attempting to insert them into the PCB. Press the switch fully down onto the PCB before soldering each pin. Also fit REG1, taking care to orientate this correctly.

Mounting the pots

Before mounting the potentiometers, the shafts should be cut to length. The length depends upon the knobs and the type of box that the preamplifier is to be mounted into. The thickness of the front panel will have an impact on the required shaft length.

Make sure the motorised pot (VR1) is seated correctly against the PCB before soldering its leads. Once the pot fits correctly, solder two diagonally opposite pot terminals and check that everything is correct before soldering the rest. The two gearbox cover lugs can then be soldered.

That done, connect the figure-8 wire to the motor terminals along with the 10nF capacitor that also connects to these terminals.

These leads pass through a hole in the board immediately behind the motor. They are then secured to the underside of the PCB using cable ties and then brought up to the top side of the PCB just behind CON6.

Strip the wire ends and crimp them to the header pins. The wire from the positive motor terminal (marked with a red dot) should connect to the CON6 pin that is closer to IC5. Insert the pins into the 2-way shell and plug it into the CON6 header.

Before fitting VR2 and VR3, scrape off some of the coating on the top of the pot body using a file so that they can be soldered to. Don't breathe in the resulting dust.

VR2 and VR3 must be seated correctly before being soldered to the board. They are then earthed using 0.7mm diameter tinned copper wire soldered to the GND PCB stake and the top metal shield on both pots. Make sure that you apply sufficient heat for the solder to form a good joint.

Mounting the LEDs and IRD1

We mounted the infrared receiver IRD1 with its lens about 18mm above the PCB. Similarly, the LEDs were mounted with the base of the LED body 18mm above the PCB. This will allow sufficient length for the LED leads to be bent forward, to line up with the potentiometer shafts, and then poke forward through the front panel of the amplifier.

When bending the LED leads, keep in mind that the longer (anode) leads must go into the pads marked "A" on the PCB. IRD1 should be fitted with its hemispherical lens facing towards the front of the board.

The assembly can now be completed by installing the spade connector to the left of the motorised pot. It is secured with an M4 screw, shake-proof washer and nut.

Leave the ICs out of their sockets for now. They are installed later, after the power supply checks have been completed.

Conclusion

Next month, we'll describe the Input Selector module and Switch Board assemblies and detail the test procedure.

We'll also have more details on the power supply arrangement and describe how the remote control is set up. SC

Resistor Colour Codes (all three PCBs)

	Qty.	Value	4-Band Code (1%)	5-Band Code (1%)
❑	2	1MΩ	brown black green brown	brown black black yellow brown
❑	9	100kΩ	brown black yellow brown	brown black black orange brown
❑	2	22kΩ	red red orange brown	red red black red brown
❑	1	18kΩ	brown grey orange brown	brown grey black red brown
❑	2	12kΩ	brown red orange brown	brown red black red brown
❑	5	10kΩ	brown black orange brown	brown black black red brown
❑	1	2.7kΩ	red violet red brown	red violet black brown brown
❑	19	2.2kΩ	red red red brown	red red black brown brown
❑	4	1.8kΩ	brown grey red brown	brown grey black brown brown
❑	10	1kΩ	brown black red brown	brown black black brown brown
❑	2	330Ω	orange orange brown brown	orange orange black black brown
❑	13	100Ω	brown black brown brown	brown black black black brown
❑	1	22Ω	red red black brown	red red black gold brown
❑	3	10Ω	brown black black brown	brown black black gold brown

PRODUCT SHOWCASE

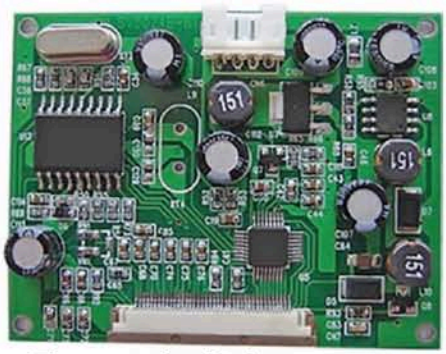
RayMing does much more than manufacture PCBs – they assemble them too!

RayMing is a PCB Manufacturer with ten year's exerience. In addition, RayMing can also provide one-stop PCB manufacturing and PCB assembly.

Based in Shenzen, China, RayMing has two types of PCB assembly services: full and partial turn-key services.

Full Turn-Key covers all aspects of PCB fabrication and assembly, from manufacture of PCBs, parts procurement, quality inspections through to final PCB assembly.

In *Partial Turn-Key*, the customer is responsible for supplying the PCBs and a partial list of parts. RayMing will order the remaining parts and perform the assembly according to the customer's requirements.



They can also kit the parts.

RayMing Technology uses a variety of testing methodologies to ensure the assembled boards are functional prior to shipping, with ISO 9001 Quality Certification.

The methods include:

1. *Basic Quality Test* – visual inspection.
2. *X-ray Inspection* – tests for BGAs, QFN and bare PCBs.
3. *AOI Checks* – tests for solder paste, 0201 components, missing components and polarity.
4. *ICT (In-Circuit Test) / Functional test* – according to the customer's testing procedures.

There's much more information on RayMing's website.

Contact:
RayMing Technology
Robotics Indust. Park, Fuyong, Shenzen, China
Tel: 0011 86 755 2734 8087
Web: www.raypcb.com

4-digit displays have many uses

Manufactured by Akytec, the ITP11 4-digit, 7-segment LED display is designed to be connected to any pressure, temperature or other transmitter with a 4-20mA output.

Measuring 24 x 48mm, it requires no auxiliary power, being supplied directly from the current loop.

The measured values are scalable and there is also an optional square root function for flow applications.

Unlike displays from other manufacturers that require a rectangular hole cut in the cabinet or enclosure to mount it, the ITP11's compact, standardised design fits into a standard 22.5mm borehole for signal lamps.

This provides quick and easy installation and many displays can be accommodated in a control cabinet door or on a panel.

The display is available in red or green and it can be programmed to flash if the level reaches an alarm state.

Other LED display models from Akytec feature voltage, RTD, thermocouple and Modbus inputs.

Contact:
Ocean Controls
44 Frankston Gardens Dve, Carrum Downs, 3201
Tel: (03) 9708 3290
Website: oceancontrols.com.au

400GbE OSFP I/O connectors now at Mouser

Mouser Electronics, Inc., is now stocking OSFP input/output (I/O) connectors from TE Connectivity (TE).

TE's next-generation octal small form-factor pluggable (OSFP) connectors are designed for maximum thermal and electrical performance in data center applications.

TE's OSFP connectors deliver 400 Gigabit Ethernet (400GbE) speeds over eight electrical lanes to support equipment that operates at up to 56 gigabits per second (Gbps) PAM-4 and 28Gbps NRZ.

The SMT connectors offer a 60-position interface with a two-row design on a proven 0.6mm contact pitch. Offering low PCB cost and noise, the SMT connectors are belly-to-belly capable with in-ground alignment.

OSFP cage assemblies feature a flat rock PCB assembly and support 1×1 and 1×4 single-port and multi-port applications.

Contact:
Mouser Electronics
Web: www.mouser.com/te-osfp-io-connectors

Microchip's development kit for Amazon AVS

Voice control is increasingly becoming a preferred way for consumers to interact with electronics.

Microchip Technology Inc., via its Microsemi Corporation subsidiary, has introduced AcuEdge ZLK38AVS Development Kit for Amazon Alexa Voice Service (AVS) to help designers build devices with one-mic hands-free and two (180° linear) or three-mic (180° linear or 360° triangular) far-field configurations qualified by Amazon.

It includes the ZL38063 audio processor which connects directly to a Raspberry Pi 3B with plastics and mounting hardware to simulate a typical, recommended end-application mic-speaker arrangement.

The field-programmable, field-upgradable solution features signal processing algorithms proven to improve both local trigger detection performance and cloud speech recognition accuracy.

The multi-micro-phone configurations include Direction of Arrival (DOA) estimation to indicate where the primary voice sound source is located. SC

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BUILD-IT-YOURSELF DAB+ Digital Audio Broadcasting WITH FM, AM and a Touchscreen Interface using an Explore100

The DAB+/FM/AM Radio is complete. In our last exciting episode, ~~we had left the heroine tied to the railroad tracks~~ (woops, sorry, wrong episode) we had just finished assembling the radio PCB, leaving us with quite the cliffhanger!

Part 3: By Duraid Madina and Tim Blythman

If you're building our fantastic new DAB+/FM/AM radio, after following the instructions in the article last month, you will have a completed Explore 100 module and digital radio board.

We now need to put those together and into a case, and load all the required software to get it up and running.

While you're reading this article, be sure to check out the updated screen grabs, as the software is now complete and it looks much better than the 'work in progress' interface shown in the last couple of articles.

Final assembly

The following instructions assume that you are building the radio into our custom-designed laser-cut acrylic case.

If you are not, the general assembly of the 'stack' will be much the same, but you will be omitting the acrylic parts. The case arrangement is shown in Fig.3.

You might think that it would be a good idea to test the whole stack before completely assembling it, but we found that it needs to be held rigidly together to ensure that all the connections between the boards are good.

So we suggest that you put it all together before testing and programming it. It isn't difficult to get apart if you run into problems later.

Start with the front acrylic piece, with the large cutout for the LCD screen. Put an M3 x 32mm machine screw through each corner hole and secure them to the panel with M3 Nylon nuts.

The panel is not symmetrical; the small cutout for the touch panel cable is the most obvious indicator. So check that the screws are the correct way around relative to the LCD panel before securing them with the nuts.

Feed the 5-inch touchscreen assembly over the machine screw shafts so that its front sits nearly flush with the front of the acrylic front panel. Attach it to the front panel by threading 12mm tapped spacers over the machine screws.

Now feed the assembled Micromite Plus Explore 100 module over the over the machine screw shafts, ensuring that the header on the touchscreen board seats into the header on the Micromite board. The Explore 100 module is then secured by four 9mm tapped spacers over the screw shafts.

Next, fit the 15mm tapped spacers over the remaining stubs of the machine screws.

You may have noticed that you have a spare 20x2 female header socket with long pins (it was in parts list). This is used to bridge the gap between the Micromite board and the radio PCB.

We've seen a few versions of these with different lengths, so you may find you need to trim the pins, or you might even be able to replace CON3 entirely and solder the header with long pins directly to the radio PCB.

However, we do not recommend that you try to de-solder CON3 if you have already fitted it to the board, since you're likely to damage the board in the process. In that case, you're better off using the intermediate header, as we did.

The radio PCB sits flush against the M3 x 15mm tapped spacers (24mm from the Micromite board), so you can judge at this stage how the headers between the Micromite board and

the radio PCB will fit. In any case, ensure that the connection between the Micromite board and the radio PCB is solid.

To finish the case assembly, rest the partly assembled stack with the screen facing down (it's a good idea to set it on a sheet of blank paper or a clean cloth to protect it).

Slot the longer, narrow acrylic pieces in place. The one with the single squarish hole goes over the IR receiver. Slot it into the front panel, then tilt it over the IR receiver; you may need to gently bend the IR receiver to suit the hole.

The other long, narrow acrylic piece goes along the opposite edge of the front panel, with the cutouts matching the small three-pin header for the serial port (to program the Explore 100) and the microSD card socket (to load the Si4689 firmware). With these two panels in place, the two side panels can now be fitted.

The side panel with four round holes is for the side with the RCA sockets. Slot the tabs in the front panel, then tilt into place over the side tabs. The RCA sockets protrude, so it will be difficult to get this on the wrong way.

The remaining small panel fits on the other side. Similarly, the antenna socket protrudes, so slot the panel into the front and tilt up to engage the tabs in the adjacent panels.

At this stage, you'll have a large piece of acrylic, four 25mm-long machine screws and four 15mm-long tapped spacers left. You'll also note that the large piece of acrylic has a long slot on one side and two short slots along the opposite edge; these align with the tabs on the back of the side panels.

While appearing symmetrical, the back panel is not. The long slot goes on the side near the RCA connectors (and is needed due to their location in that side panel).

Thread the 25mm machine screws through the mounting holes in this rear panel and fit the 15mm tapped spacers to their threads. Tighten the spacers until they are almost, but not quite tight; we need the machine screws to be able to rotate to complete the last step.

Finally, line up the back panel by placing its machine screws into the holes in the corner of the radio PCB, and tighten them up, ensuring that the tabs are correctly captured in the slots.

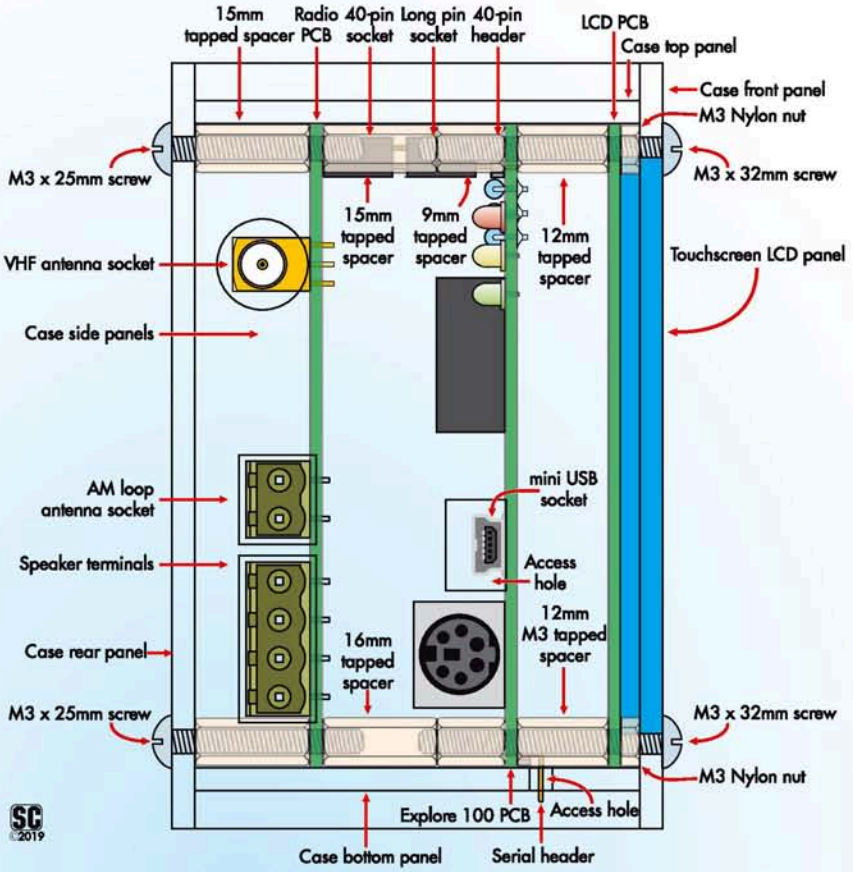


Fig.3: this shows how the three PCBs (LCD, Explore 100 & Radio) are joined using tapped spacers and pin headers. The top, bottom and sides of the case are sandwiched in between the front and rear panels, which are held rigidly together by the whole stack.

At this stage, the external telescopic antenna and AM loop antenna can be attached, and a set of headphones or other means of testing the audio plugged in.

Loading the software

The first step for installing the radio software and firmware is to load MMBasic onto your PIC32 chip (if it isn't pre-loaded) and then load the radio's BASIC source code into it.

The software for this project is available for download from the Silicon Chip website. The ZIP package includes the BASIC source code, two HEX files and the Si4689 firmware file.

Most constructors will already have the Micromite firmware installed on the PIC32 in the Micromite Plus Explore 100 module, as they will be building it from a kit with a pre-programmed chip.

If instead you have a blank PIC32 and need to load MMBasic yourself, you will need a PICkit 3, PICkit 4 or Microbridge (described in May 2017; siliconchip.com.au/Article/10648).

The August 2016 article on the Micromite Plus has some information on programming the PIC32 chip with a PICkit, on page 68; see siliconchip.com.au/Article/10040

After that, you will need to configure the LCD screen, touch panel and SD card to work as noted in this article. The steps to do this are listed below. But first, we'll explain how to program a blank PIC32.

You can upload the firmware HEX file to the microcontroller using the in-circuit serial programming (ICSP) header on the Explore 100 board. This can be done with a PICkit or Microbridge.

You can either load a plain Micromite HEX file, in which case you will also need to load the BASIC code later, or use a HEX file specifically for the radio project which contains MMBasic and the radio code.

If using a PICkit, plug it into the ICSP header with pin 1 (arrowed) lined up on both plug and socket, then launch the Microchip MPLAB IPE software (included with the free MPLAB X IDE download).

Connect to the PICkit and select

Changes to the final circuit and PCB

While testing the radio, we found that we needed to make some minor "tweaks" to the circuit and the PCB design, which were presented in the January and February issues.

You may remember from the first article that the AT25SF321 32Mbit serial flash chip is wired both to the flash SPI interface on IC1, the Si4689 radio IC, and also to pins 5, 8, 10, 12, 14, 16 & 20 on CON3, the Micromite Explore 100 interface header.

As we explained then, while the Si4689 can read its firmware straight off the flash chip via its direct interface, we need the Explore 100 to communicate with the flash chip directly, to initially write the firmware into it. And we may also need to write a new firmware later, if an update becomes available.

We planned to set the connected Explore 100 pins as high-impedance inputs after programming the flash chip, allowing the Si4689 complete control over the flash.

But unfortunately, due to the high frequencies that it uses to communicate with the flash chip (to load the firmware quickly), even with the Explore 100 pins in a high-impedance state, these extra connections still caused problems.

We found that the Si4689 would sometimes fail to boot or worse, boot a corrupted copy of the firmware and then crash when specific radio functions were activated.

We tracked this down to the parasitic inductance/capacitance of the long tracks on the Explore 100 board connecting these pins (the intervening connectors don't help, either).

The resonance and antenna-like properties of these tracks caused overshoot and ringing on the flash SPI lines when they were being driven by the Si4689, interfering with its ability to read the firmware data off the flash chip.

Our solution was to insert four resistors in series with the FLSO, FLSI, FLCK and FLCS lines of the flash SPI bus, between IC3 and CON3. We placed these close to IC3, keeping the tracks between IC1 and IC3 short. This solved the booting problem.

We determined that the ideal values are 2.2kΩ for the data lines (SO and SI) and 100Ω for the clock (CK) and chip select ($\overline{CS}$) lines.

These have been added to the final version of the PCB, close to IC3 and inside the radio box at upper-right. They will be pre-soldered to those boards which have been ordered with IC1 and associated parts already fitted.

We have decided to supply the flash chips pre-programmed with the firmware, on those boards which are supplied with the chip fitted.

In theory, those resistors could be removed once the flash chip is programmed, leaving flash chip IC3 only connected to the radio chip, IC1. However, you would then lose the ability to write a new firmware image to the flash chip (we're not sure if there will be any firmware updates in future).

Because we program the flash chip from the Explore 100 at a fairly slow rate (it takes a couple of minutes to write around 2MB), these extra series resistors do not interfere with that process at all.

the correct chip type (PIC32MX-470F512L). Load the HEX file, then power up the Explore 100 board and press the program button.

Check the bottom of the window. It should tell you that the chip has been programmed and correctly verified. If you got an error, check that the programmer is wired up correctly and that you don't have any soldering or component errors on your Explore 100 board.

The process with the Microbridge is similar except that you use different software. See the May 2017 article for instructions on how to program a PIC32 with a HEX file using pic32prog.

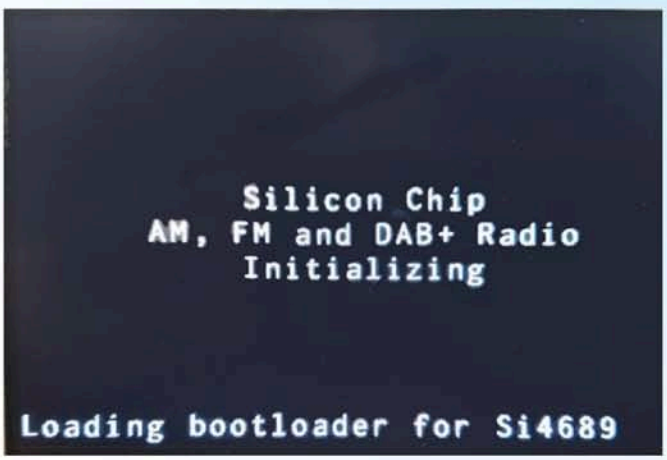
Setting up the touchscreen

Your chip should now be programmed with MMBasic. If you used the HEX file with the radio code included, the touchscreen will be configured, but you may still want to calibrate the touchscreen to ensure its touch sensing is accurate.

If you have programmed it with plain MMBasic, you will also need to set up the LCD controller and SD card.

These steps can all be done using a computer's USB port. You can also use this connection to load the BASIC code, as described below. Note that the micro-USB connector on the Explore 100 CON1 (if installed) only supplies power, so you will need to use the mini-USB connector (CON2) for this task.

This, in turn, requires that JP1 be set to provide power from CON2. You should also take care that no other power supplies are connected, as they



Screen1: at power up, the radio displays a simple splashscreen. After initialising the digital audio transceiver chip, the radio feeds the bootloader code into the Si4689 radio IC, as shown here, and it switches to the main screen once this chip is ready for reception.

Screen2: the main radio screen, in DAB+ mode. 204.64MHz is channel 9B, one of four DAB+ frequencies used in Australia, and WSFM is one of the channel 9B services in Sydney. The channel text is displayed below this (it scrolls so you can read it all), with the reception power of 49dBμV shown above. The + and - buttons select different services while the << and >> buttons change frequency.

may back-feed the computer through CON2.

Alternatively, you can use a USB-Serial Module connected to the serial port pins (GND/TX/RX) on the Micromite instead, with external power.

If you are using Windows 10, macOS or Linux, then you should not need any special drivers on your PC.

For earlier versions of Windows, you can download the SILICON CHIP USB Serial Port driver from http://geoffg.net/Downloads/Maximite/Silicon_Chip_USB_Serial_Port_Driver.zip or from siliconchip.com.au/shop/6/930

You will need a terminal program such as TeraTerm or PuTTY. Find the serial port of the Micromite and open this port with the terminal program. The baud rate is unimportant, as it is merely a virtual serial port.

After opening the serial port, press enter and you should see the text prompt ">" appear, possibly along with a boot message. To set up the LCD screen, type the following command:

```
OPTION LCDPANEL SSD1963_5,
 LANDSCAPE, 48
OPTION SDCARD 47
GUI TEST LCDPANEL
```

You should then see coloured circles appear on the screen. Press the spacebar to stop the test. Then run the following commands to set up and calibrate the touchscreen:

```
OPTION TOUCH 1, 40, 39
GUI CALIBRATE
```

You only need to run the last command above if your screen has already been set up. Use a stylus or similar to press accurately on the targets that appear in each corner of the screen. You should get a message like "done." to indicate that calibration was successful. If you get an error message, try again.

Loading the BASIC code

If you programmed the PIC32 with the HEX file that already contains the BASIC code, you can skip to the next section. Otherwise, you will need to load the radio code onto the Micromite chip.

Note that the 'uncrunched' (ie, including comments and whitespace) version of the BASIC program is too large to be loaded into the Micromite's flash memory, so the 'crunched' version must be used unless you are using a program like MMedit, which supports automatic crunch-on-load.

In the terminal, type "XMODEM RECEIVE" and press Enter. Use the terminal program's menu to send the BASIC file using the XMODEM protocol.

In TeraTerm, this can be done by choosing the File Transfer → XMODEM → Send.. menu option and then selecting the file.

After a few seconds, you should get a message that the program has been saved.

Now type "RUN" and press Enter. The program will start and display diagnostic information in the terminal window, and the Micromite display panel should show its startup messages too. While you might not be ready to use the unit just yet, this step ensures that the AUTORUN flag is set and the program will start when power is applied.

By the way, it is also possible to get the BASIC code onto the Micromite by loading it onto a microSD card, plugging it into the Explore 100 and using the LOAD command.

Loading the radio firmware

In addition to the MMBasic software that runs on the Micromite, providing the radio user interface and controlling the Si4689 radio IC (IC1), there is also software (firmware) that needs to be loaded into the radio IC itself.

While it is possible to get the Explore 100 to read this off an SD card and load it into IC1, that's a slow process, so it is also stored on serial flash memory chip IC3.

Three firmware images need to be loaded into IC1, one for each radio reception mode (DAB+/FM/AM). There is also a so-called "bootloader" image which is loaded directly from the Micromite, which allows IC1 to load the main firmware images by itself.

The bootloader is just 940 bytes, so it fits comfortably in the Micromite's own flash memory, and since it's small, it's fast to load in this way (the main firmware images are around half a megabyte each). This 940-byte bootloader then loads a larger 6kB bootloader from the serial flash IC, and that is then used to load the larger firmware images.

If you have purchased the kit from the SILICON CHIP ONLINE SHOP, your flash chip should already be programmed with the necessary firmware images. So you just need to load

Screen3: the main screen with the radio in FM mode. You can see that the RDS data has given us the station name and currently playing song. The SNR and received power figures are shown just below the tuning control, which is surrounded by the fine and coarse tuning buttons and scan up/down buttons. The eight channel presets are below, with the mute and volume control to their right.

Screen4: in AM mode, there is no text display or station name; we simply show the tuned frequency, signal-to-noise ratio and received power figures. The Standby button switches the radio and screen off but leaves the micro powered up, so you can wake it up by touching the screen or pressing the power button on the remote control.

the software into the Explore 100 (see below).

If you do not have a pre-programmed flash chip, there is a routine in the supplied Micromite BASIC code which can do this for you.

By the way, we're storing the 940-byte bootloader as binary data encapsulated in a "CFUNCTION" in the BASIC code.

But it isn't really a function; it's just a blob of data that we can read out of the micro's flash memory and feed to the radio IC.

Programming the flash chip

If you need to program the flash IC with the radio IC's firmware, this can be done from the unit itself, although it does require the firmware images to be placed on a microSD card, so that they can be copied.

They consist of four files with .bin extensions (see Fig.3). Copy them to the root directory of a microSD card and plug it into the Explore 100.

Power the radio on from a USB socket (so that the diagnostic serial data can be viewed) and allow it to boot. Open the serial port and press the Config button on the main screen.

There is a button labelled "Write Flash". Press this to start the process of copying the files from the microSD card to the flash IC.

The "Write Flash" button will change to say "Writing..." and the process will take around five minutes.

You should see the button change to "Write Done" when the process is complete.

The serial port will also display the progress of the write as follows:

```
erasing flash chip:
 please wait...
flash chip erased
writing FM radio firmware
 to flash...
writing DAB radio firmware
 to flash...
writing AM radio firmware
 to flash...
writing Loader firmware
 to flash, copy 1 at 0x2000
writing Loader firmware
 to flash, copy 2 at 0x4000
```

If you see something very different or an error is reported, then the write has not completed correctly. You should check that the connections between IC1 and IC3 are correct, especially the four series resistors (see panel). If the write completes successfully, then the programming is complete.

Setting up the radio

As you can imagine, the DAB+/FM/AM radio is full of features which we will now explain in detail.

On power-up, a splash-screen is displayed while the various systems are initialised (Screen 1). After a few seconds, the main screen appears and the radio is ready to use (Screens 2-4).

In the AM and FM modes, there is one station or program at each frequency. But with DAB+, multiple "services" (which can have multiple components) coexist on the same frequency.

There are few frequencies used for DAB+ (four in Australia), so the radio only needs to search for services inside this limited range of frequencies, rather than seeking across an entire band, as with AM or FM.

The top half of the radio display (inside the large frame) is responsible for tuning and band control, as well as the selection of digital radio services. Some of the buttons only appear in certain modes; some of the tuning buttons do not appear in DAB+ mode, while the service selection buttons are not visible in the AM or FM modes.

Tuning

The buttons around the frequency display near the top of the screen are used for tuning. The "+" and "-" buttons change the frequency in small steps, akin to fine-tuning. In AM mode, for example, these are 1kHz steps. This is mainly useful for correcting small errors when entering a frequency using the keypad.

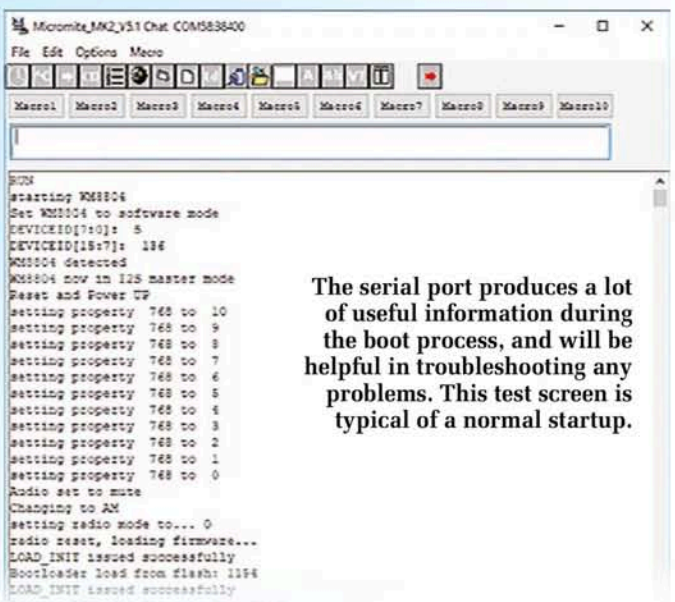
The next buttons, "<" and ">", tune in larger steps: 9kHz for AM and 0.1MHz for FM. These would generally be used for manually stepping through the frequency band, listening for stations.

The outermost buttons, "<<" and ">>" are used for seeking. They will step the frequency down or up until the radio finds a station. This is done by the radio chip internally.

In DAB+ mode, these are used to switch between the four channels. By default, the radio is set up for the Australian DAB+ frequencies, but you can change this in the settings if you are overseas.

If you try to seek but the radio cannot find any stations, you can press one of

Screen5: the configuration screen gives you some checkbox (on/off) options at upper left, LCD backlight control settings, a locale setting (to determine which DAB+ frequencies are used) plus an error log display at right and a button to write new firmware to the serial flash chip (IC3).



The serial port produces a lot of useful information during the boot process, and will be helpful in troubleshooting any problems. This test screen is typical of a normal startup.

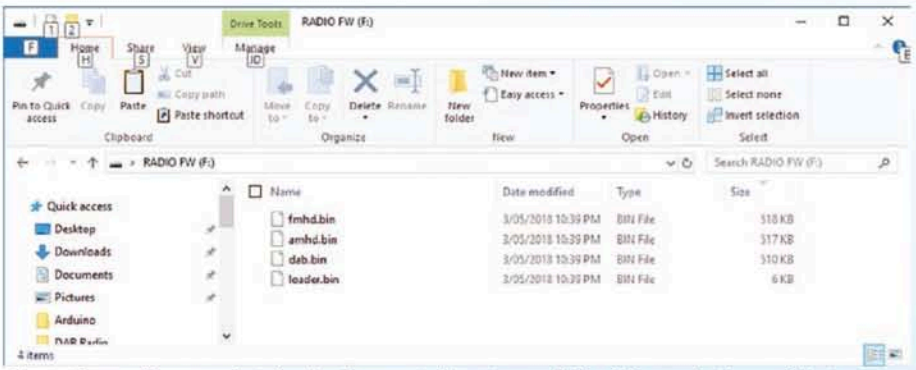


Fig.4: these files need to be in the root directory of the SD card plugged into the Explore 100 module before you can program flash chip IC3 with the radio firmware. You could also copy the basic file and use the LOAD command

the tuning buttons again to cancel the seek. Note that all the other buttons are disabled while a seek is occurring.

The frequency display can also be touched to manually enter a station frequency using an on-screen numeric keyboard. Sensible bounds are provided to prevent invalid values being entered.

In the DAB+ mode, the buttons next to the upper frame are available, and these are used to cycle through the available services on a given frequency. There is no specific order to these services; they are listed in the order that they are detected by the radio chip, IC1.

The smaller frames below are used to indicate station information and, if available, information about the current program (eg, which song the station is currently playing, or the latest news or weather).

AM broadcasts have no facility for carrying program information, so the station information is limited to the tuned frequency in this case.

In FM mode, it displays the tuned frequency by default, but if RDS (Radio Data System) is available, this will carry the station name which will then be displayed. RDS data usually also contains program information, which is displayed in the lower frame.

When DAB+ mode is active, the upper frame displays the service name, with the lower frame showing program information, if available.

There are also small numerical displays indicating the received RF power and either signal-to-noise ratio (SNR; in AM/FM mode) or signal quality (in DAB+ mode).

Despite DAB+ transmissions being vertically polarised, we found DAB+ reception to be best with the antenna horizontal while FM reception was best with the antenna vertical.

You may need to experiment with antenna orientation and positioning to maximise reception. Keep the AM loop antenna away from the radio and ideally, near a window.

Station presets

Below the tuning controls, eight preset buttons provided, which can be set to any station, band or service. A long press on one of these buttons (for more than one second) will store the currently tuned station or service to that preset.

The button caption is changed to match the name displayed in the upper frame, which may be a frequency or text if this is available from an RDS or DAB+ service.

A short press activates the preset, changing band, frequency and service as necessary.

Any time a station or service is saved, all of the current settings are saved to flash, so that they are reloaded the next time the radio starts.

To the right of the presets are the volume and mute controls. The volume level is remembered while muted, although the control is disabled and can't be changed until mute is disabled. The volume scale is from zero to 63 (loudest), as this is what the radio IC uses internally.

The radio can detect when headphones are plugged into the jack socket, and any connected speakers are automatically muted when headphones are plugged in.

Since the stereo amplifier driving the speakers has its own volume control, volume for the headphones and speakers can be set independently.

This saves your ears from being blasted when plugging headphones in (although it's always a good idea to put them on after plugging in) and is also convenient since you can set a comfortable default level for both outputs.

Because IC1 is not able to deliver digital and analog audio outputs simultaneously, if you want to use the digital outputs, you will need to enable them using the Dig Out button on the main screen.

It is automatically disabled when headphones are plugged in, so that the headphone output can produce sound, and this also has the beneficial effect of automatically muting any speakers connected to the digital outputs.

Settings

At the bottom right of the display is the "Config" button, which will take you to a separate Settings page. Pressing the "Main" button will then return to the main radio screen. Whilst on the Settings page, the radio will continue doing whatever it was doing last, so you can continue listening to the last tuned station as you fiddle with the settings.

As well as providing some configuration options, this page also includes an error log, which can be used to help debug the unit in the absence of a serial terminal display. If the message "No Errors" is seen, chances are that everything is working normally.

If multiple errors are indicated, pressing the up and down arrows next to the display will cycle through the text description of the errors found. Practically all the errors that can be shown will involve IC1, the main radio IC.

We've also mentioned the "Write Flash" button above in the setup section. There is little need to use this after the radio is operational, but we hope that there will be future firmware upgrades to the Si4689 radio IC to expand its features, in which case this can be used to write the newer firmware to the flash

We'll briefly explain what each of the settings does now. There is a "Save Settings" button in the top right corner. While most settings will take effect immediately, they will not be saved automatically; they must be saved if you want them to be retained after a power cycle or reset.

There is a backlight dimming control which can be used to reduce the backlight brightness after the display is not touched for the delay period. As soon as the display is touched, the

maximum backlight intensity is set.

The maximum cannot be set any lower than 20%. This prevents the screen from becoming unreadable.

The "Digital Output" checkbox disables analog audio when selected (and no headphones are plugged in), allowing the digital audio outputs to be used.

There is also a setting to swap the left and right analog outputs, in case your speaker or headphone channels are swapped. And there's a setting to force mono output in cases where you may only have one speaker, eg, if you've built the radio into a box with an internal speaker.

And there's also an option to enable "quiet mode", where SPI traffic and CPU activity is kept at a minimum, to maximise reception, especially for AM. Note though that when this is enabled, you will not get an FM RDS or DAB+ station information display.

Remote Control

In addition to the touchscreen, the unit can also be manipulated using a universal infrared remote control. We have included code to allow many of the functions to be controlled by an Altronics A1012 or Jaycar XC3718 remote control (others may be suitable, but we have not tested them).

Many, but not all of the features can be accessed from the remote control. Since there is no easy way to tell a long press from a short press, stations cannot be preset, but existing presets can be selected using the remote control.

The BASIC program has space for custom remote codes, and also displays the codes it receives to the serial monitor. Thus, if you're interested in modifying the BASIC source, you can easily find out what codes are being transmitted by your remote, and use them to add functions to your radio.

By default, remote control buttons 1-8 select between your presets, with the volume and mute controls providing their standard functions. Seeking can be accomplished with the channel up and down buttons, and switching bands is done by the AV button on the Altronics remote.

Since the Jaycar remote lacks a mute or AV button, the play/pause button is used for muting, and the "CH" button provides band switching.

You can also enter an AM or FM station frequency manually using the remote control, by first pressing the "200+" (Jaycar) or "OK" (Altronics) button, then typing in the frequency. Then press the 200+/OK button again to tune to that station, or standby/on/off on the Altronics remote to abort.

The Jaycar remote should work out of the box, but the Altronics remote needs to be set to use AUX code 171. This is done by pressing and holding the SET button, then pressing the AUX button and releasing the SET button. When the LED illuminates, enter the code 171 using the number keys, and the LED should go out.

Refer to the remote control manual for more detail on the programming process. You will need to press the AUX button before using the remote so that the codes are sent using the correct code.

What's next?

We've been swamped with suggestions of extra features for the DAB+/FM/AM Radio. You will have seen from the first part of the series that we have even included a header to attach a potential expansion board and connections to the audio multiplexer to allow an alternate source of audio to be fed to the output stages.

We don't yet have any firm plans for what (or even if or when) will be added here. The expansion header was designed with the intent of allowing a WiFi-equipped board (such as one based on an ESP8266) to be attached, and be able to provide access to internet radio stations.

But there are so many possibilities for expanding or enhancing the radio that we couldn't possibly investigate all of them properly.

So, we put the call out to you, dear reader.

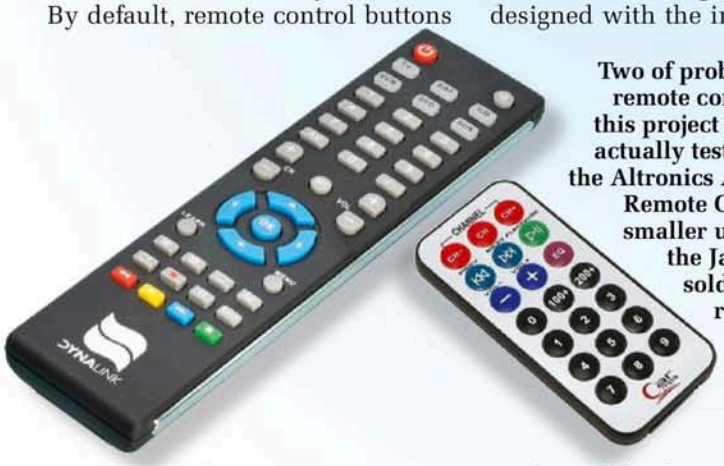
We challenge you to add features to the radio. The source code is available to those subscribers constructing the project, and the expansion header makes changing the hardware easy (and reversible).

Take great care if you are considering changing the interface with the radio IC. It's easy to "break" the code, although you probably won't damage anything; going back to the original software should at least get your radio going again.

Adjust the user interface if you like. The colour scheme is simply set by numerous CONSTs at the start of the code, so this aspect can quite easily be changed if you prefer a different feel.

If you come up with a useful enhancement, please send it in.

We may publish it in Circuit Notebook, or even its own article, if it's significant enough. We look forward to seeing what you come up with. SC



Two of probably hundreds of remote controls suitable for this project (the only ones we actually tested). On the left is the Altronics A1012 "Universal Remote Control" while the smaller unit on the right is the Jaycar XC3718. It's sold as an "Arduino" remote control but works perfectly with the DAB+ radio.

DAB Receiver Parts:

The following parts for the DAB+/FM/AM Receiver will be available from the SILICON CHIP ONLINE SHOP:

Main PCB only	(SC4895)	$15.00
Main PCB with IC1 pre-soldered	(SC4896)	$60.00
Main PCB with IC1 and extra SMD parts pre-soldered	(SC4897)	$80.00
Set of SMD parts (contains most parts not included with the partially pre-assembled board)	(SC4904)	$30.00
Clear acrylic case	(SC4849)	$20.00
465mm extendable VHF whip antenna with SMA connector (mainly for DAB+)	(SC4847)	$10.00
700mm extendable VHF whip antenna with SMA connector (good for DAB+ and FM)	(SC4875)	$15.00
PCB-mount right-angle PAL socket	(SC4848)	$5.00
PCB-mount right-angle SMA socket	(SC4918)	$2.50
Dual horizontal PCB-mount RCA sockets (RCA-210)	(SC4850)	$2.50

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6.4V 4.5Ah	SB2200	**$49.95**
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Lithium Iron Phosphate (LiFePO4) batteries are the latest in battery technology. Featuring up to 10 times the battery cycle life with only half the weight of its lead-acid equivalent.

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20A MPPT solar charge controller for lithium or SLA batteries

Uses Maximum Power Point Tracking (MPPT) for maximum efficiency and charge rate. Charge lead acid (sealed, gel or flooded) or lithium batteries. 3-stage intelligent charging. 12/24V operation. MP3741

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Features built-in Residual Current Device (RCD) to protect against electrocution and equipment damage. Automatically shuts off power when a fault occurs. 240V 10A. 1.8m long. QP2006

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10A Double GPO power point with built-in RCD

Designed to be a direct replacement to your standard GPO fittings, combining two standard 240AC 10A mains (GPO) outlets with a built-in RCD to provide protection against electrical shock. LED indicators. PS4048

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Adds a compact power supply to your breadboard. Power from a USB socket or DC. 3.3V or 5V switchable. XC4606

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24V EI Core transformer

Type 2158 single winding transformer with 20mm fly leads on primary and secondary connections.

- 24V, 72VA, 3A rated

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power control

Relay modules

FROM **$12.95**

Control a motor backwards and forwards without speed control. Plenty of power (up to 10A at 30VDC), but need a separate 12VDC power supply to operate the relays. Provides isolation between the Arduino® circuit and switched circuit.
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TECH TIP: RELAYS
Relays are a great way for controlling power but aren't capable of being directly controlled by a microcontroller such as an Arduino®, but using our relay modules, this restriction is overcome.

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Mosfet driver module
Accepts Pulse Width Modulation (PWM) input to drive 24VDC loads when connected to an Arduino®. Perfect for many projects such as lighting, DC motors, pumps and solenoid.
• 3.3V & 5VDC
XC4488 **WAS $7.95**

NOW **$9.95** SAVE 20%

Motor control module
Has 2 x 5V servo ports connected to the Arduino's high-resolution dedicated timer to ensure jitter-free operation. Control up to four DC motors or two stepper motors.
• 5V to 16VDC
XC4472 **WAS $12.95**

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Dual motor controller module
Allows full control of two DC Motors or one stepper-motor. Provides 4A at up to 30V, and has an onboard 5V regulator to power your Arduino® main board.
• 3V to 30VDC
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power conversion

JUST **$4.95**

DC to DC converter module
Capable of providing a stable 5V, from a single Li-Po or two Alkaline cells. Input is via two solder pads, output is via a female USB socket.
• 34(L) x 16(W) x 8(H)mm
XC4512

JUST **$7.95**

DC voltage regulator
Accepts any voltage from 4.5-35VDC, and outputs any higher voltage from 3-34VDC. The output voltage is adjusted via a multi-turn potentiometer.
• 49(L) x 26(W) x 12(H)mm
XC4514

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DC to DC boost module with display
Can be used to provide higher voltages for your project, such as running 5V Arduino® projects from Lithium batteries. Solder terminals.
• 66(L) x 35(W) x 12(H)mm
XC4609 **WAS $19.95**

ONLY **$14.95**

5A 12VDC PWM motor speed controller kit
Ref: DIYODE Magazine March 2018
This kit is a bare bones motor speed controller for fairly low current, low voltage applications. Ideal for controlling small robotic motors or pump motors. Includes a solder-masked and silkscreened PCB.
• Silk-screened PCB: 61(L) x 36(W)mm
KD6102

ONLY **$17.95**

Universal power supply regulator
Ref: Silicon Chip Magazine March 2011
A small board and a handful of parts will allow you to create either a regulated ±15V rail or +15VDC single voltage from a single winding or centre tap transformer (not included).
• Silk-screened PCB: 72(L) x 30(W)mm
KC5501

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5V Stepper motor and driver set
Stepper motors require a series of pulses to power them. This means the speed and position of the shaft can be controlled with more precision. Comes with a dedicated driver board which can interface with the Arduino®. XC4458

FROM **$14.95**

12V Gearhead motors
These rugged units have a 12VDC motor attached to a high-torque gearbox. Use to drive wheels or even rotate appendages like an arm or head. Ideal if you want something more powerful than Chassis Kits, or already have a frame and wheels.
70RPM 2.1KG/CM YG2732 **$14.95**
36RPM 12KG/CM YG2734 **$23.95**
160RPM 75KG/CM YG2738 **$43.95**

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Servo motors with metal gears
High speed and high torque digital servos with dual ball bearings and metal gears for maximum strength and durability. Excellent replacement for the standard servos commonly used in all 1/10th and many 1/8th scale remote control cars or for use in any number of robotics applications.
6V 13kg YM2763 **WAS $34.95**
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Ideal for hobbyist or anybody interested in winding their own transformers. 56 pages.
BM2440

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BT1347

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the best project ideas

PROJECT:
Portable compass & phone charger

Have fun building this practical project for the upcoming holiday break. The addition of a functional USB output will ensure if you're lost you can use the compass to charge your phone and call for help or directions too. With this project you'll always be able to find your way home.

SKILLS: Beginner
TOOLS: Soldering iron, side cutters, hot glue gun

See step-by-step instructions at www.jaycar.com.au/digital-compass

1 × Duinotech Nano Board	XC4414	**$29.95**
1 × OLED Display Module	XC4384	**$29.95**
1 × 3 Axis Compass Magnetometer Module	XC4496	**$15.95**
1 × 150mm Socket to Socket Jumper Leads	WC6026	**$5.95**
1 × 7805 +5V 1A Voltage Regulator	ZV1505	**$1.85**
1 × Battery Bank 4 x AA USB A SKT with Switch Black	MP3083	**$4.95**
2 × Rechargeable Li-ion Battery 800mAh	SB2300	**$9.95 EA.**

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• SAA approved

Straight IEC Female to 240V Male - 1.8m	PS4106	**$8.95**
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FROM **$5.95**

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• SAA approved

2pin Mains Plug to IEC C7 Female - 1.8m	PS4115	**$5.95**
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2 metres of 8 different colours of 13 x 0.12mm hook- up wire.16 metres in all. WH3025

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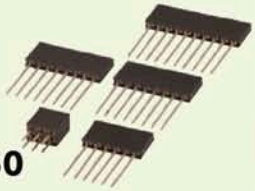
Power cables
PVC insulation. Sold by metre or 100m roll.
Flexible Light Duty 13 x 0.12mm. 0.6A.
WH3010 - WH3017 **$0.25/m or $15/roll**
Heavy Duty 24 x 0.2mm. 7.5A.
WH3040 - WH3042 **$0.55/m or $42/roll**
Extra Heavy Duty 32 x 0.2 mm. 10A.
WH3050 - WH3052 **$0.80/m or $72/roll**



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Build a stackable shield, or make your current shield stackable.
1 × 10-pin, 2 × 8-pin, 1 × 6-pin, 1 × 2x3-pin (for ICSP). HM3208

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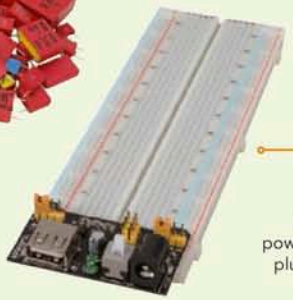

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830 tie-point breadboard with removable power supply module. Power from USB or 12V plugpack. Includes 64 mixed jumper wires of different length and colour. PB8819

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12V Deep cycle gel cell SLA batteries

Leakproof and completely sealed, ideal for solar power, 4WD, camping etc.
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NA1420 $9.95

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200A DC watt meter power analyser with LCD display

All-in-one power meter, volt meter, amp-hour meter, ammeter and energy meter. Designed for systems less than 60V and currents up to 200A (Peak).
• 75A continuous / 200A Max
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DC power meters with built-in shunt and LCD display

Self-contained. Suitable for solar systems up to approximately 2kW (must not exceed 20A). Bright blue backlit display. Real time information.
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Shuts off power to the connected device if the voltage drops below 11.6V. Suitable for loads up to 10A. MB3677
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Protects your car battery from total discharge by switching off appliances before the battery voltage drops to an unrecoverable level. 12V 20A.
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125A dual battery isolator (VSR)

Protects your starter battery. Automatic operation. Ideal for 4WD, marine, and more.
MB3687

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12/24V PWM solar charge controllers

Efficient, automatic. Advanced digital technology which increases battery lifetime and improves solar system performance. IP67 rated.
12/24V 10A MP3756
WAS $59.95 NOW $39.95 SAVE $20
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Modified sine wave inverters

INTRO PRICE! **$59.95**
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150W cup type

The World's Smallest Cup Inverter™. 150W continuous, 300W peak
• 4 x 2.4A USB ports
MI5020 **ORRP $69.95**

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200W powerboard

2 x 230VAC ports and 4 x USB ports to charge your phones, Tablets and other tech. Also has cigarette lighter socket to power other 12V devices.
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500W

• 500W continuous, 1000W peak
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Energizer.

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500A Jump starter & 7500mAh powerbank combo

Jump starts a car, motorbike or boat 8 times with one charge.
• Built-in Li-Po battery
• 2.4A USB port
MB3770 **ORRP 119**

JUST **$19.95**

4-Way splitter with USB

Power up to four 12VDC plug appliances at once (max 10A). USB socket (max 1A). PS2019

JUST **$26.95**

Dual 2.1A USB charging ports

Supplied with panel and surface mount hardware, to easily mount inside your car, caravan, truck etc. Includes removable dust cover. PS2030

JUST **$29.95**

3-Way cigarette lighter socket with USB & voltmeter

Power up to 7 devices! 12-24VDC. Simultaneous charging. Voltage warning. Overcharge and overcurrent safety protection. PP2120

JUST **$34.95**

USB and 12V cigarette lighter power socket (switched)

Features an on/off rocker switch under a protective tamper-resistant cover. Will behave like a circuit breaker if current draw exceeds 16A, and can be immediately switched on again! PS2036

NI-MH

PLUG-IN STYLE WALL CHARGER **$42.95**

Ni-MH battery charger with 4 eneloop batteries

Charges both AA and AAA batteries and includes 4 x AA eneloop batteries. Approx. 10 hour charge time. MB3563

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• NI-MH
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4-Channel universal battery charger

Compatible with most types of rechargeable batteries. Charges Li-ion, Ni-MH and Ni-Cd batteries.
• 1A USB outlet
MB3701

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SAVE $10

• LIPO
• LIFE
• LIHV
• NI-MH

Universal compact balance charger

Balance charging provides greater control over the cells being recharged to help promote longevity and prevent overheating.
MB3629 **WAS $59.95**

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working with a solar charge controller:

The best way to connect a battery to a solar panel or array is with the use of a solar charge controller because solar panels can output a wide voltage range. While directly connecting a solar panel to a battery will actually charge it, there are problems. A solar panel can put charge directly into a flat battery, but it tends to want to keep putting charge into the battery even when it's NOT flat. This can cause the battery to overheat or even burst open. If nothing else, it will drastically shorten its life. The second problem is poor efficiency: A sizeable part of the light energy captured by the solar panel(s) winds up heating up the solar cells, instead of charging the battery. To overcome these problems, you need some sort of Solar Charge controller. They come in three basic types.

SWITCHING:
Most economical. Simply monitors the state of battery charge and disconnects it when the battery is full.

PWM (PULSE WIDTH MODULATED)
More expensive. Has a proper charge regulator but panels must match batteries (eg 12 Volt batteries must have 12 Volt panels). Commonly built into portable solar arrays.

MPPT (MAXIMUM POWER POINT TRACKING)
Most expensive and heavier but best. Similar to PWM but has "intelligence" to make most efficient use of solar power available, plus solar panel voltage can be higher than battery voltage.

PWM

NEW

JUST **$14.95**

12V 3A miniature

Compact, suitable for many small solar applications and suits 12V solar panels. 3-stage charging. Light and timer control. MP3762

FROM **$39.95**

12/24V with USB

Lightweight, suitable for 12V and 24V battery banks. USB charging port provides up to 1.2A charging. Supports sealed, gel and flooded type batteries.
10A MP3750 **$39.95**
20A MP3752 **$69.95**

NOW **$54.95**

SAVE $15

12/24V 10A dual battery with LED indicator

Highly efficient. Charge 2 separate battery banks at the same time. Electronic protection from over charging short circuit or accidental reverse battery connection. 12/24V auto detect. MP3760 **WAS $69.95**

NOW **$79.95**

SAVE $20

12/24V 30A with LCD screen

High efficiency and reliable. Detects 12V or 24V inputs automatically and can be left on permanently. LCD backlit display. Dual timer.
MP3754 **WAS $99.95**

MPPT

FROM **$129**

SAVE UP TO $50

12V/24V with LCD screen solar charge controller

Highly intelligent. Microprocessor controlled. Works with 12V or 24V systems. LCD Display.
- Automatic load control with low-voltage disconnect/reconnect
- Twin timer programming
- Overcharge, overcurrent & under voltage protection

15A MP3739 **WAS $149 NOW $129 SAVE $20**
30A MP3735 **WAS $249 NOW $199 SAVE $50**

NOW JUST **$299**

SAVE $50

12V-48V 50A with LCD screen solar charge controller

Highly intelligent for use with solar arrays up to 95VDC. Works with 12V, 24V, 36V or 48V systems. LCD Display.
- Adjustable bulk and float charge voltages
- Heavy duty terminals
- Overcharge, under voltage & reverse current protection

MP3731 **WAS $349**

FROM **$4.95/m**

Solar PV power cables

Dust, age and UV resistant, tinned copper conductors to minimise corrosion.
- IP65 rated

50A 4.0mm² WH3121 **$4.95/m**
70A 6.0mm² WH3122 **$7.95/m**

ONLY **$7.50 ea.**

4mm Waterproof solar power PV connectors

IP67 rated for maximum environmental protection.
Male PP5102
Female PS5100

NEED A CRIMPER?
See our TH1834 $14.95

ONLY **$9.95 ea.**

50A power connectors

Used widely in both domestic and industry applications. Supplied as a moulded 2 pole with contacts.
- 50A, 600V (AC or DC)

6 Gauge PT4420
8 Gauge PT4425
10-12 Gauge PT4427

FROM **$14.95**

50A high current leads

Easily adapt or extend your 50A Anderson connector with the following 300mm long adaptors or 5m extension.

Eye Terminal 300mm	PT4444 **$14.95**
Cigarette Plug 300mm	PT4446 **$16.95**
Cigarette Socket 300mm	PT4448 **$16.95**
Piggyback 300mm	PT4442 **$34.95**
Plug Extension 5m	PT4440 **$79.95**

ONLY **$19.95 ea.**

Solar panel 'y' leads

Used for connecting the output of two solar panels in parallel or connecting multiple panels in an array. Waterproof and UV resistant.
2 Sockets to 1 Plug PS5110
2 Plugs to 1 Socket PS5112

your destination for

your workbench power essentials

$179
SAVE $20
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1. **Variable laboratory autotransfomer (variac)**
   - Heavy-duty steel housing
   - 500VA (fused) rated power handling
   - 0~260VAC @ 50Hz output voltage

   MP3080 **WAS $199**

2. **Cat III insulation tester/ multimeter**
   - Suitable for high voltage insulation testing up to 4 gigaohms at up to 1000V.
   - AC/DC voltage, low resistance functions
   - Moulded storage case and holster included

   QM1493 **WAS $249**

3. **Power point and earth leakage tester**
   - Multiple testing options
   - IP65 rated enclosure
   - Buzzer & LEDs for quick diagnosis

   QP2004 **WAS $34.95**

4. **3000A True RMS AC clamp meter**
   - Massive 3000A current measurement
   - Flexible "clamp" loop
   - CATIII 1000V and CATIV 600V rated

   QM1568 **WAS $69.95**

5. **Cat III non-contact AC voltage detector**
   - Detects AC voltages from 200 to 1000V
   - LED flashlight function
   - 2 x AAA batteries included

   QP2268

6. **3-30VDC tester with voltage/polarity readout**
   - Works on 6/12/24V systems
   - Stainless steel testing probe
   - LED Indicators: Green (-), Red (+)

   QP2216

FROM $59.95
SAVE UP TO $50

Fixed laboratory power supply
High current general workshop power supplies for equipment, component testing, etc. 13.8VDC.

12A MP3079	**WAS $69.95**	**NOW $59.95**	**SAVE $10**
20A MP3078	**WAS $99.95**	**NOW $79.95**	**SAVE $20**
40A MP3089	**WAS $199**	**NOW $149**	**SAVE $50**

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Variable laboratory power supply
High current, variable output and fan cooling. Protects against thermal overload and short circuit. Display a warning LED in the event of a fault condition. Backlit analogue meters.
0-24VDC 15A MP3800 **WAS $149 NOW $129 SAVE $20**
0-16VDC 25A MP3802 **WAS $199 NOW $169 SAVE $30**

NOW $299
SAVE $50

Regulated laboratory power supply
Highly efficient & reliable for testing and servicing applications. 0-15VDC variable output voltage. 0-40A variable current limiting. Overload and over temperature protected.
MP3091 **WAS $349**

quality soldering irons & accessories by goot.

goot®

NOW $69.95
SAVE $10

85W 240V soldering iron
High quality iron. Exceptional heat recovery. 320°C tip temperature.
- Japanese made

TS1430 **WAS $79.95**

CARBON STEEL
ONLY $12.95

127mm precision side cutters
Easily cut leads ideal for fine PCB work. Soft padded handles. TH1897

STAINLESS STEEL
ONLY $13.95

145mm long nose pliers
Perfect for adjusting and bending components, picking up dropped nuts, etc. Soft plastic handles. TH1893

ONLY $5.95 ea.
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SERVICEMAN'S LOG

My father, the ultimate "serviceman"

Dave Thompson

Once again we are into another year, and while most of us are focusing on getting back into the swing of things, for me, 2019 began with sadness. My dad Gary, the man who taught me so much, finally downed tools, passing away on December 20th, 2018. Ironically, it was the brain that gave him his skills and intellect that ultimately failed him, gradually robbing him of his talents.

Items Covered This Month

- The ultimate serviceman
- Dishwasher repair
- Tractor display module repair

Dave Thompson runs PC Anytime in Christchurch, NZ.

Website: www.pcanytime.co.nz
Email: dave@pcanytime.co.nz

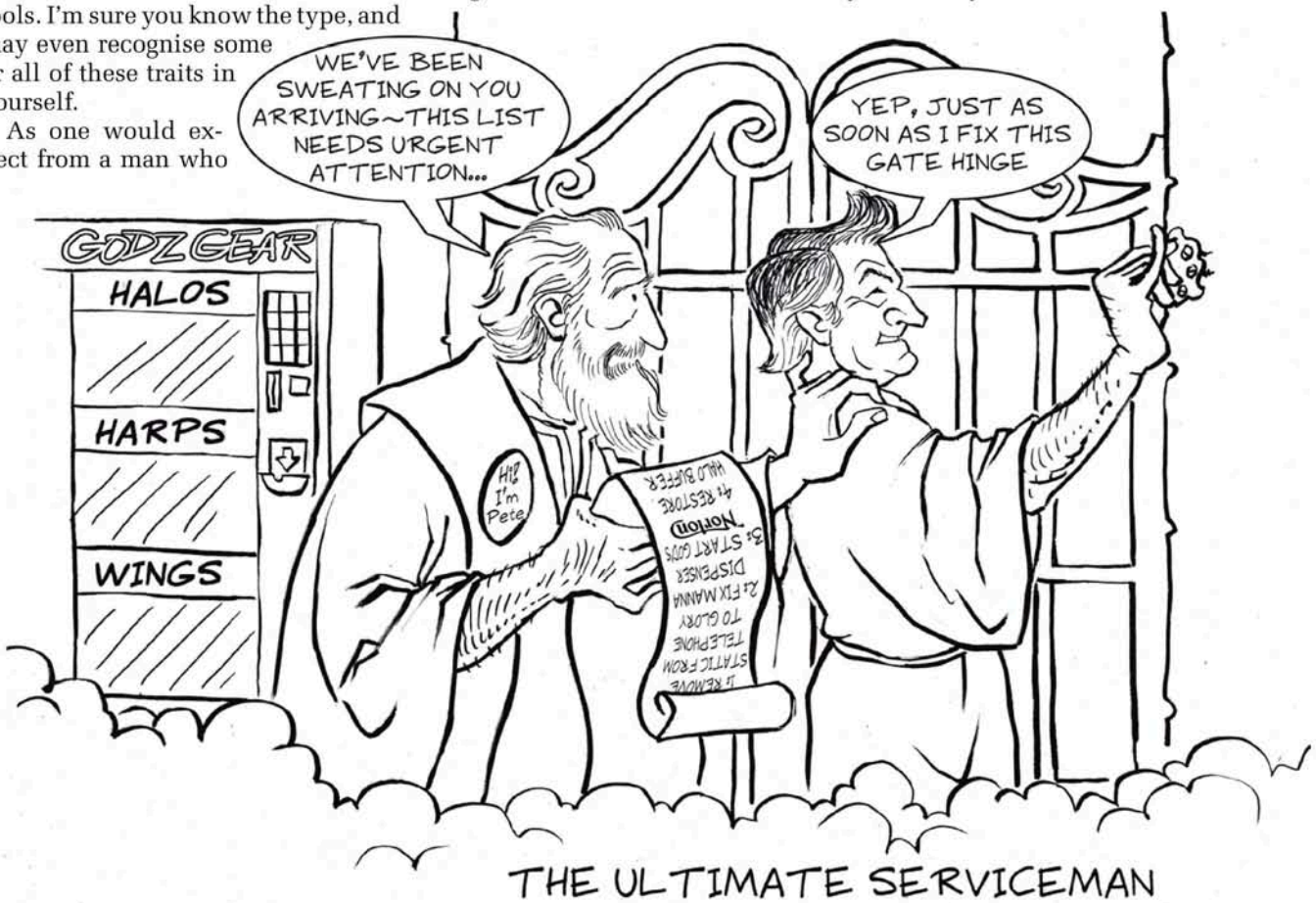
I've met many amazing and extremely clever people in my life and even some I would not hesitate to call a genius. My largely self-taught Dad stands tall among them.

All of these people share common traits; an endless thirst for knowledge, a desire to learn anything new, a need to find out how something works and enviable skills with all manner of tools. I'm sure you know the type, and may even recognise some or all of these traits in yourself.

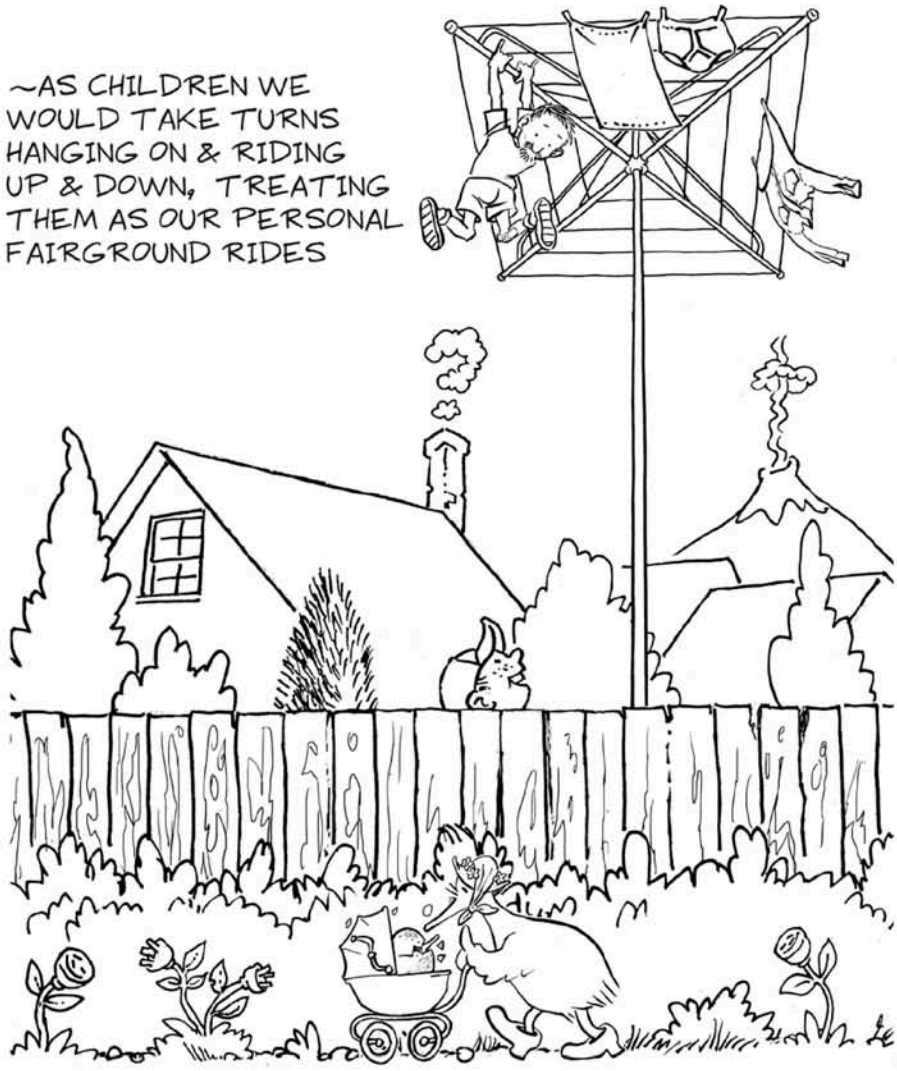
As one would expect from a man who lived for over eight decades, Dad had some intriguing and usually entertaining engineering and serviceman-related stories to tell.

The problem was that I heard most of them from family members or friends; Dad was a man of few words and he didn't waste any of them blowing his own trumpet. If pressed, he might sometimes confirm or modestly disclaim some of the details, assigning positive outcomes to 'luck' or somebody else who was involved, but I'd like to believe the stories were all true.

I could fill a book with these anecdotes, and might just do that one day. One example: it wasn't until I made my first electric guitar at 18 that Dad informed me that he too had made one in his youth. Dad didn't have a musi-



THE ULTIMATE SERVICEMAN



cal bone in his body (some may argue that I don't either!) but that didn't stop him making his own instrument.

While I utilised a lot of donated or store-bought hardware, he fabricated almost everything on his guitar – the bridge, pickups and even the machine heads! The desire to do this most likely came more from a position of not having a lot of money or a source of suitable components than anything else. But ANZACs in his peer group have a well-deserved reputation for "doing it themselves".

While Dad never had a full-time job as an actual serviceman, he'd built a reputation as a person who could repair or fabricate just about anything. So he ended up doing a lot of repair and custom work.

Someone once gave him a broken Bakelite and brass steering-wheel bezel from a vintage car to restore but as it was too far gone, he hand-fabricated a whole new one from period materials. Word slowly got around the global vintage car community (this was the 70s) and soon he was making bespoke car parts for enthusiasts all over the world.

Nowadays, people can get whatever they need made in China or India, or maybe even 3D print it, but back then the only option (other than finding an original part) was to get an engineer to make one for you.

While I don't think he did a huge amount of this particular work, this is typical of how he could easily shift gears and take advantage of opportunities that came his way.

Some clever inventions

While I was around for a lot of his working life, I heard anecdotes at his funeral about his younger days that were news to me. I would have dearly loved to have discussed them with him to get more details.

I knew he'd built several electric vehicles in the late 60s for a business 'up north', and also built an electric cart and trailer that ferried tourists around the Christchurch Botanical Gardens for decades. But where he got the plans or even the parts for these vehicles, I have no idea.

I recall being very proud when as a lad I saw him being interviewed by a reporter about these EVs on the family's first black-and-white television (that Dad had also made).

I was also aware he designed and made height-adjustable rotary clotheslines for both his mother and my mother using hydraulic rams; at the turn of a water tap, the ladies could raise the washing line to almost double its normal height, catching more sun and breeze in an increasingly fenced-in and crowded suburbia.

As small children we would take turns hanging on and riding up and down these washing-lines, treating them as our own personal fairground rides (much to the adults' consternation!).

At the service, I also heard about a colossal quilting machine Dad built from scratch and installed in a textiles factory some time in the late 50s or early 60s, all from a single photograph taken by the factory owner of a similar contraption operating in America.

This sewing-machine-on-steroids followed configurable tracks built into the factory floor to create patterns in the material and was apparently used well into the 80s.

Yet another custom machine mentioned was one I had better memories of; designed and built in the late 60s, it made both solid and hollow fishing rod blanks from great reels of fibreglass strands.

The solid blanks this machine produced would later be repurposed for CB-radio whip antennas, when Dad and another guy ran a business designing, assembling and installing their own CB radio (the Telstat Minicom) during the mid-70s CB boom.

I can actually remember this machine and the reels of glass threads taking up half the space of an old gutted house Dad rented at the time. I mainly remember the heat and smell from the machine; to this day, the smell of fibreglass takes me back to that old house.

Any of these ideas, with the right backing, could make someone a fortune. But for Dad it was more the challenge of coming up with an idea, making it a reality and then moving on to the next project.

Creating anything similar today, even with all the plans, knowledge and experience on-tap via the internet would be tough going; back then, all Dad had was his hands, his imagination and a

well-equipped workshop. One must respect a man with such abilities.

A flair for repair

Another story told at his funeral, which has since been corroborated by one of the parties involved (who also happens to be a from-day-one SILICON CHIP reader), occurred way before my time and involved an innovative impromptu repair, something that Dad was very good at, even as a younger man.

The story goes that Dad had recently turned 15 and gained his driver's licence. He was hooning around Christchurch in an old Whippet sedan with his younger brother Roger when the car lost power and a knocking noise was heard coming from the motor.

Dad apparently had a good idea of what it was likely to be and proceeded to climb under the car and drop the sump from the engine right there on the roadside.

For as long as I could remember, and until only recently, Dad always carried a four-inch Crescent shifter around in his trouser pocket. Perhaps he had one with him even then.

He visually confirmed they had run a big-end bearing, which for the majority of us would be the end of the line. Not one to be beaten by a simple bearing failure, Dad asked for his brother's brand-new leather belt and to Roger's horror, he proceeded to cut it up, fashioning a new makeshift bearing from it. He then bolted everything back together and replaced the oil, which he had kept.

Off they went on their merry way and the engine was said to be still going well when they sold the car. I wonder if they mentioned the leather bearing to the new owner...

In one of life's strange coincidences, one of Dad's school-mates ended up being my foreman at the airline I worked at, and he would occasionally regale me with stories about youthful scrapes he and Dad got into.

He recalled that one fine day they were out riding their prized motorbikes in the countryside when his bike suddenly clattered to a stop in a cloud of smoke. Something was obviously wrong with the engine, and as they were a fair way out of town, this was potentially very inconvenient.

Again, not wanting to be thwarted by a measly motorbike engine failure, and using the toolkit that came with his own motorbike, Dad stripped the dead motor down by the side of the road. He soon had it reassembled and running and they both made it home.

His mate couldn't recall precisely what was wrong with the motor, and when I asked Dad about it, he said he'd found it had a blocked oil line and put it down to a fluke that he found the problem and managed to get it going again.

Harking back to my younger days

It's no wonder that I grew up with the confidence that no matter what predicament we as a family got into, Dad would find a way to get us out of it.

When I was younger, I always drove cheaper cars, preferring to spend my meagre disposable income on electronic components, model planes and tools. Of course, this is a false economy, as cheap cars tend to break down a lot.

I was always adding bits and pieces to these cars, usually from projects out of the likes of *Everyday Electronics*, *Practical Electronics* and *Electronics Australia* (obviously I spent a lot of money on magazines as well!).

The usual mods would be to add a capacitor-discharge ignition, wiper delay units, hazard flashers, a car alarm and any other easy-to-build widget or gadget I could afford to install. This taught me a lot about systems and the importance of good construction.

Dad taught me to solder when I was old enough to know which end of the soldering iron to hold onto without getting hurt, so this was never an issue, but I did have a lot to learn about installations.

Dad to the rescue

In one older (and frankly rubbish) car I owned, I'd installed a stalk-mounted high/low beam switch. This car usually had a floor-mounted dip switch and as that switch was failing, I decided to mount one up by the steering wheel, just like all the more modern cars of the time.

Since the advent of sourcing wiring diagrams for cars with a simple internet search was about 30 years away, I busied myself instead by 'ringing out' the existing wiring with Dad's multimeter.

Cars back then are not like cars today, with massively-complicated wiring looms, computers and cosmetic panelling getting in the way, but at the time it seemed complex to me.

I finally isolated the wiring for the switch and the lights and ran a couple of wires in parallel from the floor switch to the new toggle switch I'd mounted to the steering column using a hose clamp. When I'd wired it all in, the new switch worked perfectly and I was well pleased with myself.

However, a few nights later I was out and about and when I switched the lights on, the fuse blew and I had no headlights. As I had no spare fuses, I walked to a nearby telephone box (remember them?) and called Dad. He jumped in his car and came out to where I'd parked up and brought a torch and some spare fuses with him.

After installing one, we tried the lights but blew the fuse again. Dad then used the torch to have a quick look at the work I'd done and soon found the culprit; the switch had slowly moved under the metal clamp and this had bridged the terminals to ground. He removed the clamp, allowing the switch to dangle and replaced the fuse.

This time everything worked, and I won't forget the look I got as he explained that taking the time to mount components properly and insulating any bare terminals is always a good idea!

One afternoon and in yet another ageing car, I had the misfortune of the engine cutting out in the middle of a large roundabout.

The passenger and I pushed the car into the grass centre of the roundabout and after a quick look under the hood to determine the cause, I concluded I had no spark. The CDI ignition that I'd proudly built and installed a month back must have failed.

Servicing Stories Wanted

Do you have any good servicing stories that you would like to share in The Serviceman column? If so, why not send those stories in to us?

We pay for all contributions published but please note that your material must be original. Send your contribution by email to: editor@siliconchip.com.au

Please be sure to include your full name and address details.

Once again I made the call of shame to Dad. He soon turned up in his car and asked why, if I suspected the new ignition, I hadn't simply bypassed it and re-wired the old system back in, which on his advice I'd left intact in case I wanted to restore the car to its original state.

I had to sheepishly admit – in front of my friend no less – that I didn't really know how to do that, having not taken much notice of how it was before I rushed in and installed the other one.

Once again I got the look, and within a few minutes, he had swapped everything back to factory and got the engine running. He followed me home just in case, but it was another lesson learned.

Bitten by the flying bug

His lifelong love of all things aircraft and engineering meant he was a natural aeromodeller. My brother and I also got the bug, and Dad was generous with his skills, time and money to ensure we always had the best gear available, even though we sometimes tried our best to ruin it by recklessly flying our models way too close to – if not actually into – the ground.

When I got the crazy idea to build a pulse-jet powered model, rather than talk me out of it, Dad made the gear I'd need to support it, like a die to mass-produce the thin, stainless-steel petal valves I would be burning out on a regular basis, as well as an electronic ignition system and a portable, compressed-air starter.

Lighting up the garage at night as we test-ran that extremely loud and dangerous pulse jet clamped to his band-saw table is something I won't forget in a hurry!

Possibly his crowning model-engineering achievements were the large-scale, chainsaw-motor-powered P51 Mustang model he built and flew at air shows and the gas-turbine engines he produced in the 90s.

While you can buy a commercial turbine today (at considerable expense), he built his engines himself. Initially utilising repurposed housings, ceramic bearings and impellers from car turbochargers (to handle the 100,000 RPM-plus shaft speeds), Dad experimented extensively with different materials, fabricating everything else he needed.

His engines and models broke speed records and thrilled spectators at air shows all over the country and he really pushed the limits of what a skilled fabricator in a home workshop could achieve.

All the stories and his achievements inspired me to become an aircraft engineer and electronics enthusiast. Through it all, Dad was always supportive, constantly interested and free with his time, his skills and his sage advice.

I shall sorely miss him. Thanks, Dad; job well done.

Dishwasher repair

J. F., of Ivanhoe, Vic, discovered that some repairs are not difficult, just tedious. He had to fix a basic dishwasher which had wiring that wasn't quite up to the job...

Dave Thompson's dishwasher repair story in the August 2018 issue reminds me that several years ago I virtually rebuilt the wiring on a Hoover dishwasher.

It was fitted with a mechanical rotary timer actuator located on the front of the door with bundles of leads running down the inside of the door and turning 90° to go under the base to each of the motors, solenoids etc.

The problem was each time the door was opened, the wiring bundle (with over thirty separate wires) was flexed where it came out of the door into the underside of the dishwasher.

The original cables had 75°C rated insulation and a dishwasher can get hotter than that, so over time the plasticiser evaporated and the insulation became rigid. Eventually, the wires broke and went open circuit.

At the time, I worked for a large manufacturer and the friendly maintenance electricians suggested cabling with insulation rated for 105°C (this came in a variety of colours), so it was "just" a matter of replacing each cable in turn with the higher rated ones.

I sat the dishwasher on a set of carpenter's stools to access the underside components; I was used to lying under motor cars, so this didn't seem unnatural to me. It was a laborious job but it fixed the problem and the unit lasted for many years until we renovated our kitchen.

Tractor measurement display module repair

It's good to keep your brain active even after you retire. R. M. may have given up his technician job and moved to the country but he still enjoys taking on some of the more unusual servicing jobs. Here is the story of a recent repair that involved some techniques well outside his comfort zone...

It has been nearly twelve years since I retired from my University Electronics Technician role of forty years. My wife and I moved to a beautiful little town on the south coast of Western Australia, to a small farm.

When people found what I used to do, they'd get a shifty look in the eye and say, "So you know about electronic stuff eh? I've got this (electronic, electrical, electro-mechanical, mechanical, not even remotely electronic) thing that doesn't work. D'ya think you could have a quick look at it?" Of course I do. And sometimes even manage to effect some sort of repair.

It's a good way to keep the mental gears spinning. Recently my friend Wayne, a fellow volunteer firefighter, asked me whether I could take a look at his tractor's faulty dashboard. A tractor? Who could resist!

It was a fairly new John Deere 5100R, a hulking great green beast. The display module behind the steering wheel has a row of coloured lights, two large analog dials (for road speed and engine/power take-off RPM), two smaller analog dials (fuel level and engine temperature) and a small LCD screen.

It was this LCD that was having problems. Sometimes some parts of the display would disappear and sometimes, all of it would be gone.

This display shows a lot of obscure but useful metrics; stuff that Wayne often relies upon when doing contract spraying or seeding.

The local John Deere agent said that they don't repair these display modules and a new one would cost around $2000 including GST and freight. Well, Wayne reckoned that was too expensive so he asked me whether I could fix it.

My first guess was that the LCD was connected with one of those conductive elastomer strips you see on DMM displays. Lots of vibration could have loosened it. I asked Wayne to bring the module around to my place and I then removed a few screws so I could pop open the case, giving me a better view of the LCD.

It was attached to a wide, flat grey ribbon cable that snaked down between two PCBs. Getting a look at

where it connected to the boards required more disassembly that I was willing to attempt at the time.

A quick Google search for "John Deere 5100R dashboard repair" brought up a lot of mostly useless hits, but there was a video of cheerful German techies unsoldering and replacing the display using solder paste.

I had never done that before but I was prepared to give it a go. A bit more Googling came up with a supplier for the replacement part, in Spain of all places; I passed this information on to Wayne.

Several weeks later, he was back with the dashboard display and a cardboard box containing the new LCD.

We agreed that I would "give it my best shot" but there was no guarantee that this would work. In the worst case, he'd be down $70 (the cost of the replacement LCD) and my reputation as a fix-it guru would be in tatters.

Faced with that old demon, fear of failure, it was a few days before I could work up enough courage to start the job. Finally game to give it a go, I opened the case again. The next step was to remove the pointers on the four dials so that the display panel could come out.

The dials were driven by rotary actuators mounted on the back of the PCB, directly behind the display panel. The two bigger pointers had a black disc covering the central boss, so I removed one of the discs.

I then used a pair of curved tweezers like a tiny crowbar between the panel and pointer, exerting a bit of upwards pressure on the pointer and it quickly popped off.

I repeated this technique to remove the other three pointers. I could then remove the panel and pull the two PCBs apart, which were simply joined by two multi-pin connectors that pulled apart easily. This finally gave me access to the PCB where the LCD ribbon cable attached.

The board was well made with a scattering of SMDs interconnected with frighteningly fine tracks. The whole lot was covered with a hard clear varnish as thick and shiny as the sugar glaze on a toffee apple. Except (happily) for the area where the ribbon cable was attached. And yes, it was firmly soldered to the board (or so I thought).

I had to remove the ribbon so that I could attach the new display. I gingerly touched the tip of my iron to the top of the first contact between ribbon and pad while being ready with tweezers to lift the ribbon up.

The reaction was rapid and alarming – the plastic ribbon instantly melted and squirmed away from the hot iron!

All I could do was to proceed with melting off this mucky ribbon. Having done so, it was time to examine the damage.

The end of the ribbon was a sorry sight, all twisted and gnarly. But the solder pads on the PCB were fine bright gold plated. There was no sign of any solder! The tracks, now that I could see them, were not metal but more like some sort of printed conductor.

It seems that the ribbon cable had simply been glued in place. That's an easy way to guarantee failure! It's interesting to note that the version the techs in the YouTube video were working on was definitely soldered.

I removed the remaining plastic residue using some careful scraping with a craft knife and a bit of contact cleaner.

I then polished the pads up with a touch of isopropyl alcohol and a cotton bud. I was now ready for the final act: soldering on the new LCD and ribbon. I checked it carefully and was infinitely pleased to see that it was indeed a proper solderable type.

But how would I hold it in place, accurately aligned with the pads while I applied heat?

There were a couple of components annoyingly placed so as to not allow the ribbon to lay flat. I checked the video of the happy German techs; they had an elaborate special jig to hold everything sweet.

Lacking that, I decided instead to use double-sided tape to hold it in place. I found that a thin strip of tape just below the pads held the ribbon just right.

I had previously used the syringe applicator to apply 36 little blobs of solder paste on the 36 gold pads. Now, all that I needed to do was to heat the back of the ribbon, to melt the paste.

After all that had gone before, the job that I had spent all this time working towards turned out to be quite anti-climatic. The paste melted immediately. Surface tension sucked the resultant liquid solder onto the pads. I ran the iron back and forth a few times to ensure that there were no solder bridges and the job was done!

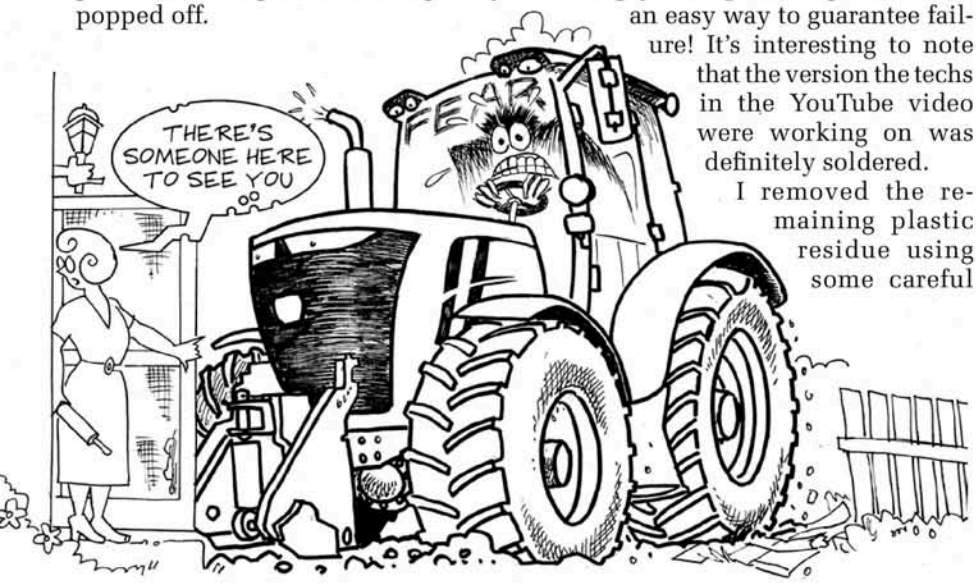
With great relief, I put everything back together. I carefully aligned the pointers on zero while the actuators were fully counter-clockwise.

When the final screws were in place and the case clicked together, I allowed myself to breathe again. Then I phoned Wayne with the possibly good news that I'd like to come over and see if the thing would now work.

He agreed cheerfully and within half an hour the module was back in place and plugged in. Moment of truth – Wayne started the engine and over the loud diesel throb I heard him exclaim, "Hey look at that! The clock works. I'd forgotten there was a clock!"

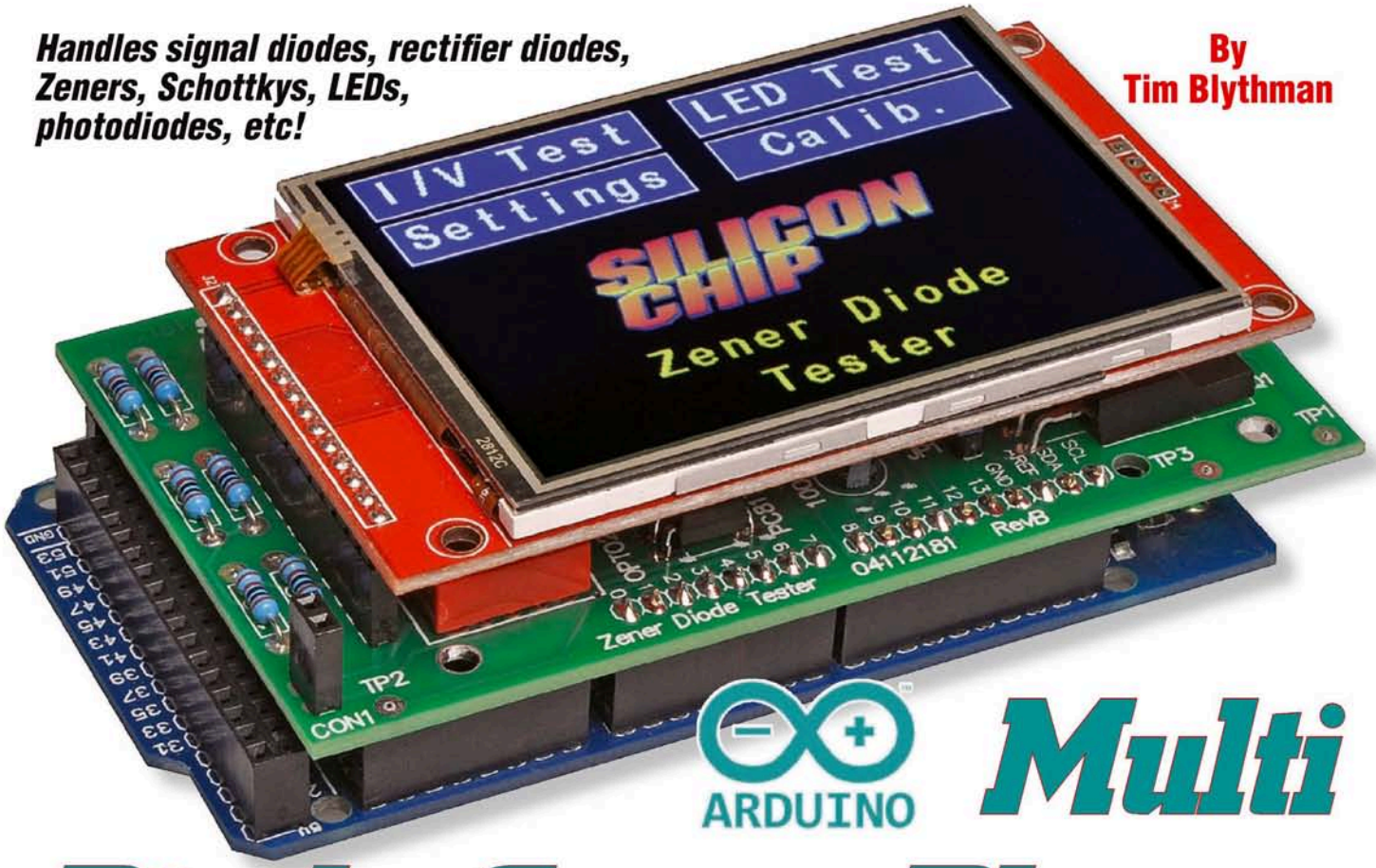
We ran through all the parameters and everything worked perfectly. Wayne was thrilled. I was immensely relieved and delighted that I'd helped a mate.

And I had kept my reputation intact. "Hey, Roy," said Wayne, "I've got this mate with a MIG welder that stopped working. D'ya think you could..." SC



Handles signal diodes, rectifier diodes, Zeners, Schottkys, LEDs, photodiodes, etc!

By Tim Blythman



Multi Diode Curve Plotter

Our new Diode Curve Plotter is *way* better than any diode testers we've published in the past; it's very versatile and fits in the palm of your hand. It automatically tests diodes in both directions and plots the resulting current/voltage curve on a colour LCD screen. It tests zener diodes up to about 100V, but it can also test LEDs, schottky diodes, regular diodes, transient voltage suppressors and more.

Our last Zener Diode Tester, published in the November 2011 issue (siliconchip.com.au/Article/1219), was beautiful in its simplicity.

But it was only able to provide a measurement of the zener voltage, and it required a separate multimeter to display the result.

This new unit utilises the same 2.8-inch colour LCD touchscreen as used in the Micromite BackPack from February 2016 (siliconchip.com.au/Article/9812), but this time it's being paired with an Arduino Mega board and a custom PCB which provides the test interface.

What it can do

The main feature of the Diode Curve Plotter is that performs a full bidirectional current/voltage (I/V) sweep of a connected diode (or another component!) and display the results in graphical form.

For zener diodes, the zener voltage and current are displayed on the screen, along with the zener impedance at that point. You can move the test point to get different voltage, current and impedance readings along the curve.

The unit can produce up to 100V at up to 30mA for testing diodes, providing a wide testing range. For devices like LEDs, you can limit the test voltage and current to avoid damaging them during testing. It also has a specific LED testing mode, to make that job even easier.

The plot data can also optionally be sent to a connected computer as rows of CSV (comma-separated value) data, allowing plots to be stored and analysed further if necessary. You can plot and analyse this data on your PC using

just about any spreadsheet program.

Getting back to the unit itself, cursors on its screen allow the operating point to be varied, by selecting either a voltage or current, allowing the operating conditions can be examined across the range of the plot.

For example, you could investigate how a zener diode performs at points away from the 'knee' of the zener curve.

The hardware scans the diode in both quadrants. It shows the full plot on the display, but only the forward operating point conditions are displayed in detail. A "Reverse" button allows the plot to be flipped so that the reverse characteristics can be checked without rerunning the test.

This is handy if the diode is connected backwards, or to check its behaviour in both forward and reverse directions.

The unit has adjustable current, voltage and power limiting parameters. But given that each test takes a few seconds to complete, even if these limits are set slightly high, any overcurrent or over-voltage condition is quite brief and unlikely to cause any damage.

The LED test mode is essentially a constant current mode, which provides a set output current and it shows the forward voltage, power and voltage/current ratio for the connected device.

The current and voltage limits can be set to the nearest milliamp and volt respectively, so even unknown devices can be probed without risk.

If a resistor is connected, the voltage/current ratio will, of course, correspond to the resistance, and thus the diode tester can even be used as a very basic ohmmeter.

Features & specifications

- Tests zener diodes, LEDs, TVSs, silicon diodes, schottky diodes and more
- Colour touchscreen interface
- Tests up to 100V/30mA from 12V DC supply (can run from 5V, including USB)
- Automatically plots I/V curve in both quadrants
- Reads out current, voltage, power and impedance at any point in the curve
- Adjustable current/power limit for smaller devices with 0.4W and 1W presets
- Simple LED testing mode
- On-screen button to show reverse characteristics
- Based on an Arduino Mega with custom shield

How it works

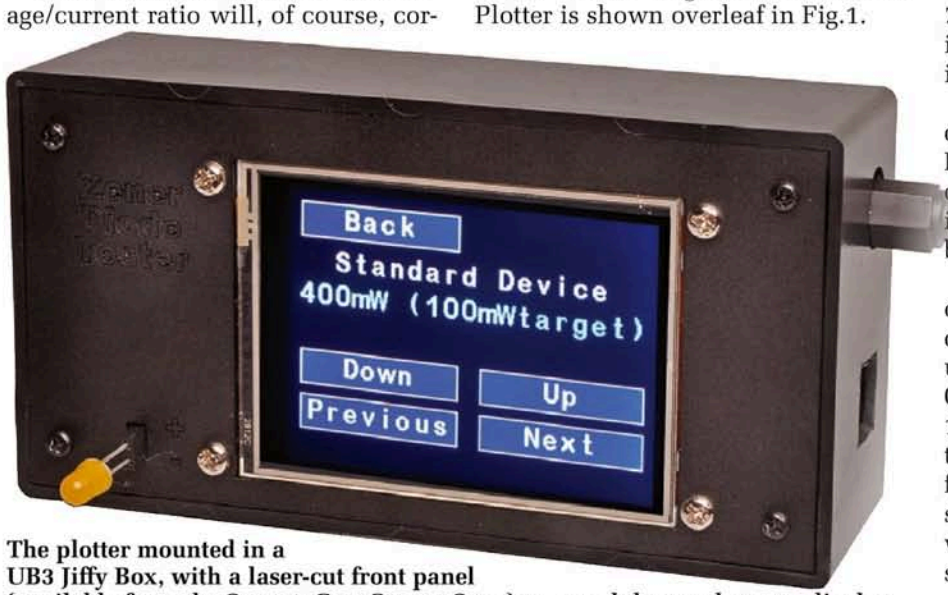
The Diode Curve Plotter is a sandwich of three boards: an Arduino Mega or compatible board forms the bottom layer and provides the processing power, the LCD touch panel is the top layer, providing display and user interface, and the custom PCB in the middle contains the other parts which measure the parameters of the connected diode.

By the way, the reason we are using an Arduino Mega rather than an Arduino Uno in this project is that we need the extra flash memory space provided by the larger chip on the Mega. We are not using any of the extra pins.

High voltage generator

As we noted, the unit can test diodes up to 100V but it runs from 5V DC, so it needs a way to generate higher voltages to apply to the device under test (DUT).

The circuit diagram of the Curve Plotter is shown overleaf in Fig.1.



The plotter mounted in a UB3 Jiffy Box, with a laser-cut front panel (available from the SILICON CHIP ONLINE SHOP) to reveal the touchscreen display.

Inductor L1, N-channel Mosfet Q1 and diode D1 operate as a standard boost converter which is driven by IC2, an LM311N comparator.

It runs from a 5V DC supply which is convenient, because that means you use a USB power bank, USB charger or even a PC/laptop USB port. But note that it may draw more than 500mA when testing higher-voltage, higher-power devices, so a computer USB port may drop its bundle under these conditions. A 1A+ charger or battery bank is recommended.

The boost regulator draws power from the Arduino's VIN pin, which is connected directly to its DC power jack. In case the unit is powered via the USB socket instead, the 5V supply flows through schottky diode D2 into the VIN rail, powering the boost converter instead.

IC2, the LM311 comparator, is used both as an oscillator to drive the gate of Mosfet Q1 and also as a current limiter. Since an LM311 can only sink current at its pin 7 output, pin D3 of the Arduino ("BOOSTCTL") must be high to enable the oscillator. This pulls pin 7 up via the 1kΩ resistor; normally, it is held low by a 10kΩ resistor, so Q1 is off by default.

Since the Arduino's D3 output is capable of generating a low-frequency PWM signal, we can switch the boost circuit on and off rapidly with a varying duty cycle to control the resulting boosted voltage.

The circuit around IC2 is not a fixed oscillator, but instead, it monitors the current passing through inductor L1 using the 1Ω 1W series resistor. When Q1 switches on, the voltage across the 1Ω resistor increases as the current through L1 builds and its magnetic field charges up, until the threshold set by the comparator's resistor network is reached. At this point, Q1 is switched off.

The 100kΩ feedback resistor pro-

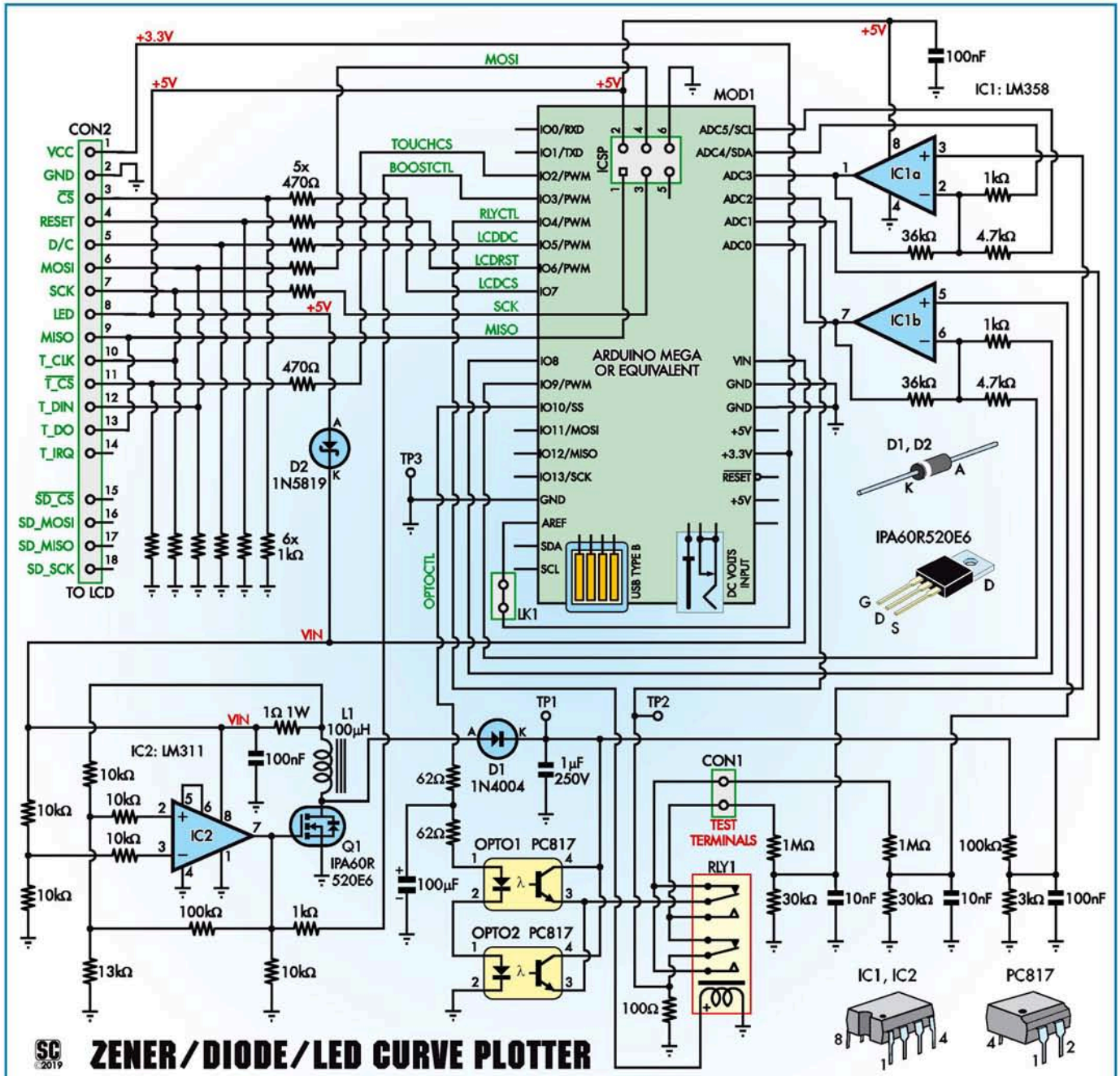


Fig.1: the Multi Diode Curve Plotter is based on an Arduino Mega (MOD1), a boost regulator (IC2/Q1/L1), two opto-isolators which operate as a controlled current source (OPTO1 & OPTO2) and a relay to reverse connections to the DUT (RLY1). The test voltages and current are fed back to the Arduino so it can plot the curve and display measurements.

vides hysteresis, allowing the current to drop a small amount before Q1 switches on again and the cycle repeats. The resulting waveform has a high duty cycle, as required for a boost circuit with such a high output/input ratio.

When Q1 switches off, the voltage at the end of inductor L1 that's connected to its drain shoots up and so diode D1 becomes forward-biased, charging up the 1µF capacitor to a much higher voltage than the incoming supply.

This voltage is divided by 100kΩ /3kΩ resistors, filtered by a 100nF capacitor and fed to analog input ADC1 of the Arduino. The divider provides a voltage which is within the 0-3.3V range of the Mega's analog-to-digital converter (ADC).

While the Mega's ADC has a 0-5V range by default, we are using its onboard 3.3V regulator as a more precise reference, and so we can measure up to around 108V with this divider. Jumper JP1 usually feeds 3.3V into its AREF pin.

This divider also discharges the 1µF capacitor, so that its charge will not persist after the boost converter is switched off. With the capacitor charged to 100V, the 100kΩ resistor dissipates around 100mW, well within the ratings of a small 1/4W resistor.

Note that the 13kΩ resistor connected to pin 2 of IC2 via a 10kΩ resistor sets the maximum inductor current (ie, in L1) which effectively determines the maximum voltage that the boost generator can produce, and also affects the maximum current that the unit will draw.

So if you want to reduce the maximum test voltage (eg, to allow the unit to run from a USB port that can only supply 500mA) then you can drop the value of this resistor to 12kΩ or even slightly lower, down to as little as 11kΩ.

Test circuitry

The test voltage is fed to the DUT via two optoisolators, OPTO1 and OPTO2, and relay RLY1. At the other end, the DUT is connected to ground via a 100Ω resistor.

OPTO1 and OPTO2 are configured as a controllable current source, with both collectors connected directly to the high voltage supply and both emitters to the DUT. Their photo-transistors are connected in parallel to enhance the amount of current they can supply to the DUT.

Their LEDs are connected in series, so that the effective current transfer ratio (CTR) is doubled. They are controlled by a PWM signal from pin D10 of the Arduino which is fed to the two 62Ω resistors. The 100µF capacitor smooths the PWM signal, in combination with those resistors, so that a steady, controllable current flows.

The modulated current goes to the DUT via relay RLY1. When its coil is energised, it reverses the connections to the DUT. The 100Ω resistor operates as a current shunt, allowing currents up to 33mA to be measured against the 3.3V reference voltage. The voltage across this shunt is monitored at the Arduino's A2 analog input.

In practice, while testing a device, the unit sweeps the test voltage with the relay switched on, monitoring both the current and voltage, then performs another sweep with the relay switched off, so that current flows through the device in both directions during a single test pass.

Measuring circuitry

There are four main parameters which are measured by the Mega's internal 10-bit ADC. Two have already been mentioned: the voltage on the 1µF capacitor and the test current, as measured using the shunt. The other two parameters measured are the voltages at each end of the DUT. Both are fed into 1MΩ /30kΩ voltage dividers, giving the same 108V maximum reading.

These voltages are fed into the two halves of IC1, an LM358 op amp. By default, these are configured as unity gain buffers, with the 36kΩ resistor in the feedback path having little effect. In this mode, voltages up to 108V can be measured with around 0.1V resolution (108V / 2^{10}).

But there is also a 4.7kΩ resistor and 1kΩ resistor from the inverting input of each op amp to two digital pins on the Arduino. These are initially left floating and in this case, do not affect the op amp's operation.

But if either is pulled low by its corresponding pin on the micro, that changes the op amp gain to either 8.66 times (36kΩ÷4.7kΩ + 1) or 37 times (36kΩ÷1kΩ + 1). This amplifies the sensed voltages, giving resolutions of around 10mV and around 3mV respectively, with the maximum readings being about 12.5V and 3V. So the gain is only increased when measuring lower voltages, to improve resolution.

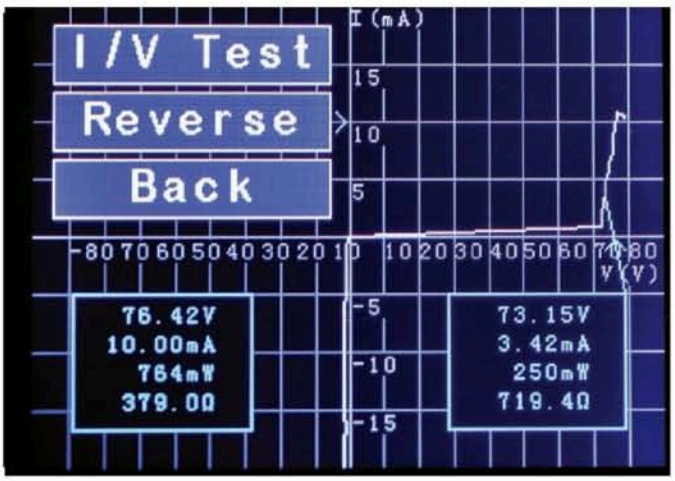
All ADC measurements are sampled 16 times and averaged to improve precision and stability.

Any error due to input offset will be taken care of during calibration stages.

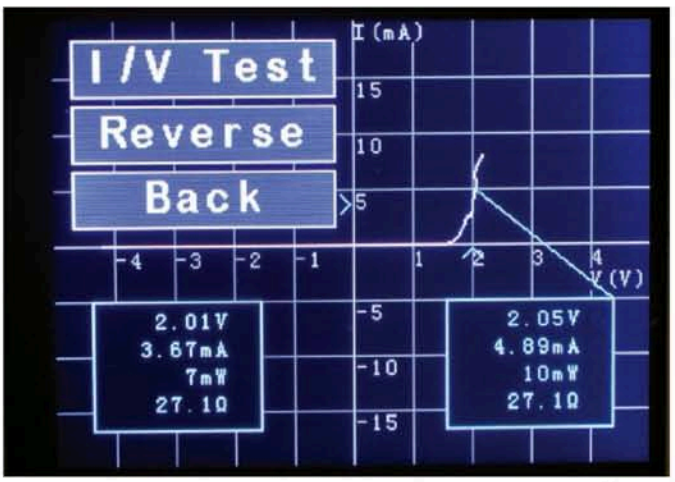
Touchscreen interface

The touchscreen plugs into header socket CON2. The

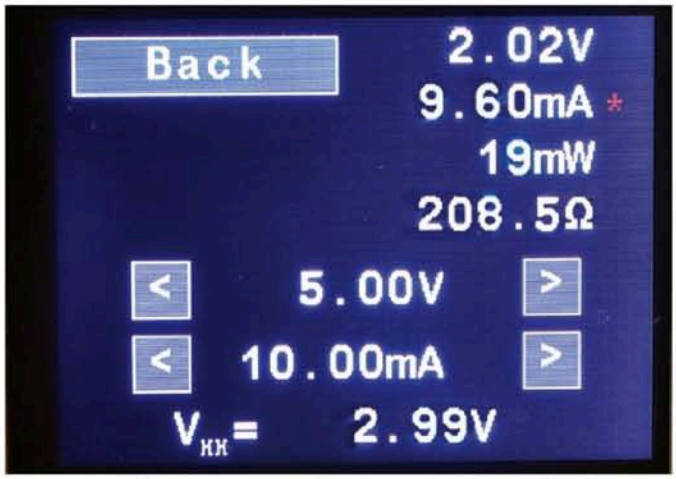
Screen1: the splash screen/main menu allows you to select between the two different types of tests (I/V Test or LED Test) and access the Settings and Calibration menus. Our logo is rendered with the glorious "Back to the Future" colour scheme!



Screen2: the typical result of the I/V Test run on a 75V zener diode. A 250mW operating point is identified and indicated on the graph.



Screen3: here we have selected the I/V Test option with a LED connected to the unit and it has performed the measurements and plotted the graph. It's showing that 10mW is achieved a forward voltage of 2.05V and a test current of 4.89mA.



Screen4: in the LED test mode where the forward voltage, current, power and zener impedance are continuously updated. You can adjust the maximum voltage and current applied to the LED directly with the arrows below.

Screen5: in the Settings screen where you can select the type of device being tested, the maximum power and the target (nominal) power. The four buttons at the bottom change these values, then you press the Back button when finished.

Screen6: the Calibration screen reads out one of seven parameters, as measured by the Arduino, allowing you to compare them to readings made with a DMM and calculate coefficients to provide more accurate measurements.

screen is powered from the 3.3V regulated supply while the backlight is powered from the 5V rail. The Arduino controls it over two SPI (serial peripheral interface) buses. One is used for updating the screen and one for getting data from the touch sensor.

Their MISO and MOSI (data) and SCK (clock) lines are connected together to share the same set of hardware SPI pins on the Arduino, via its six-pin ICSP header. The screen and touch controller have separate chip select (CS) pins, at pins 3 and 11 on CON2, so the Arduino can select which one it is communicating with by pulling one of the two digital outputs D7 or D2 low.

These five lines, plus the data/control line on pin 5 of CON2, have 1kΩ resistors connected from each pin to ground plus 470Ω series resistors between the LCD pins and the Arduino. These form voltage dividers, reducing the 5V swing on the Arduino outputs to a 3.3V swing, to suit the LCD electronics. The MISO line is driven by the LCD so no level shifting is needed, as the Arduino will read 3.3V as a high level.

The remaining five pins on CON2, the interrupt request line from the touch controller (T_IRQ) and the four SPI control lines for the SD card socket, are unused and so are left disconnected.

Software operation

While testing, the boost converter is modulated by the PWM signal from pin D3 to maintain a voltage at TP1 that's slightly higher than the desired test voltage, but within the programmed limits. Then, the current through OPTO1/OPTO2 is varied across the testing range.

The difference between the voltages measured at both ends of the DUT plus the current through the 100Ω shunt are recorded in an array.

RLY1's state is toggled to reverse the polarity of the DUT, and the test is repeated, after which the results are plotted in a graph on the screen.

The Arduino Mega interpolates the data points to find the voltage and current at which the device power equals the selected operating point. The relevant figures are then shown in a small box on top of the graph, as well as drawing lines which show where that point is on the curve.

The box display includes the voltage, current and power at the operating point, as well as the zener impedance, derived from the gradient of the voltage/current curve at that point. The raw I/V data is then dumped to the serial port, where it can be read by the PC and used for additional analysis.

The details of a second operating point can be analysed by touching the graph along the right-hand axis. If the graph is touched in the first quadrant (top right), then the current level is selected according to the vertical position of the touch.

A second info box is displayed, showing conditions at the new operating point.

Similarly, touching the graph in the fourth quadrant (bottom right) sets the voltage according to the horizontal touch position and displays a similar box.

The LED test page is much simpler, and in this mode, tests are run continuously. The current is modulated to the limit set on that page, and the voltage is maintained within these limits by controlling the boost circuit.

With more screen space available, the statistics are shown

in a larger font and they include voltage, current and power at the instant of measurement, as well as the ratio of voltage to current. This will not correspond to the zener impedance, but will be a fair measurement of the resistance of a fixed resistor.

Construction

All of the components mount on a shield PCB, as shown in Fig.2. Use this overlay diagram as a guide while building the board. Start by fitting the small (1/4W or 1/2W) resistors where shown. It's a good idea to measure the value of each batch before fitting them, as the colour bands can sometimes be ambiguous.

Solder diodes D1 & D2 in place next. They are different types and also orientated differently. Make sure that you don't mix them up and that the cathode stripes face in the directions shown in Fig.2. You can then fit the larger 1Ω 1W resistor.

Now install the seven capacitors, making sure that for the electrolytic types, the longer (+) lead goes into the pad marked with a + sign on the PCB overlay diagram and the PCB silkscreen printing.

Since the LCD stacks above this board, all components must project less than 12mm above the top surface of the PCB. If any of your electrolytic capacitors are 12mm high or taller, you will need to lay them over on their side when you fit them.

Note that we give two options for the 1µF capacitor, a polyester 'greencap' and an electrolytic type. While both should work, we prefer using the greencap, despite the fact that it needs to be installed with its leads bent over to keep it under 12mm high. Greencaps have better performance than electrolytics. But either should work, so it's up to you.

Fit the two ICs next. They are different types but come in the same package so don't get them mixed up. Fig.2 shows where they go and the correct orientation of each. Make sure the pin 1 notch or dot is facing as shown before soldering the pins. Then fit the two optoisolators, again taking care that their orientation is as shown.

Now mount Mosfet Q1. You will need to bend its legs 90° to allow the body of the Mosfet to sit flat. Before attaching to the board with a 6mm machine screw and nut, check whether that screw will foul the USB socket on your Mega board once the two are plugged together. If so, you will need to omit the mounting screw.

Once you've sorted that out, ensure the writing on the tab is facing upwards and then solder its leads. Telecom-style relay RLY1 is installed next, with its pin 1 stripe the left as shown. Then fit inductor L1, which is not polarised, so its orientation is not critical. Ensure that it is not too tall when installed; it may need to be laid on its side to keep it under the 12mm limit. Then solder pin header JP1 in place.

The four SIL pin headers for connection to the Arduino can all be snapped from a single 40-pin header. The easiest way to mount them to the board is to plug them into the Mega board, the slot the shield PCB over the top to ensure that everything is square and flush before soldering them in place. Note that they are inserted through the bottom of the PCB and soldered on the top side.

Use the same technique to solder the 2x3 female header to the board; again, it is mounted on the underside.

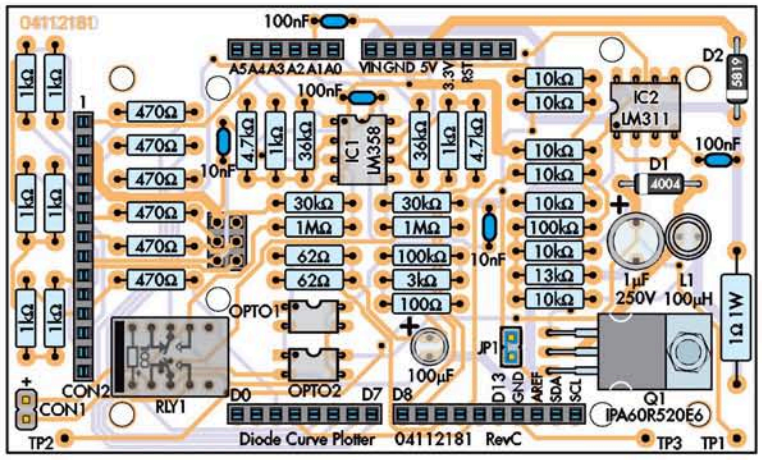
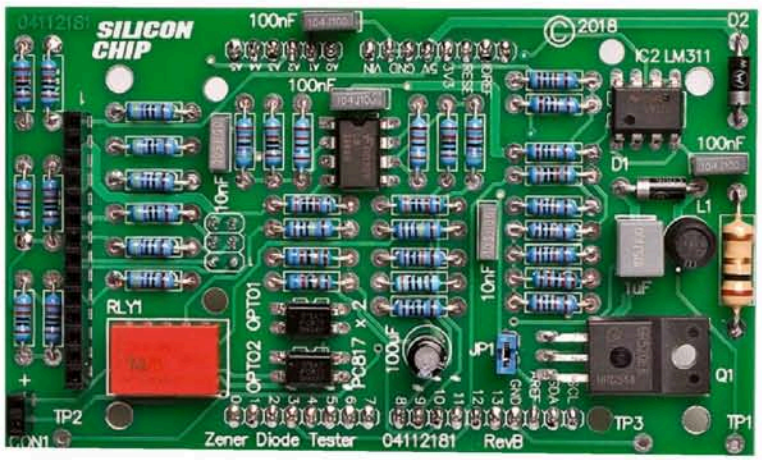


Fig.2: this component overlay echoes the silk-screen printing on the PCB surface as shown below – between the two you should have no problems constructing the shield.



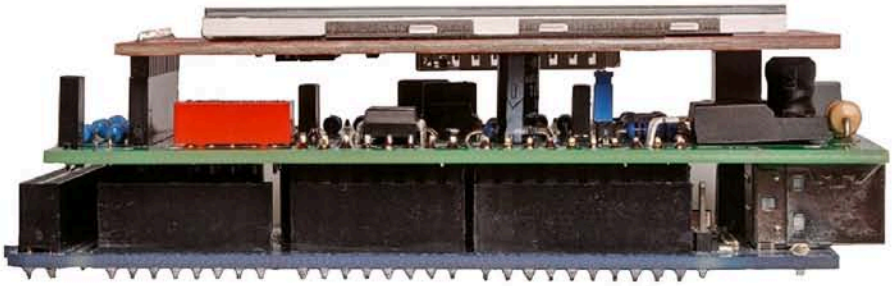
Note that you could use a stackable header set, such as Jaycar's HM3208, rather than the standard pin headers specified. But that is likely to change the overall height of the unit, and it may no longer fit in the specified case.

Use a similar technique to fit the 14-way female header which connects the LCD to this PCB. It goes on top of the board. Plug it onto the LCD header, then mount the LCD on the shield board using three 12mm tapped spacers and six 6mm long M3 machine screws – don't attach it in the upper-right corner, ie, there is no spacer mounted near IC2. Then solder the header in place.

The 2-way female header is used for CON1, which connects to the device under test. We found this type of header ideal for this purpose, as most smaller component leads simply plug into the sockets. However, you could chassis-mount banana sockets instead, and wire them back to the pads for CON1.

You may wish to solder extension leads to the pins of CON1 before fitting it, to make the top of the socket level with the top of the LCD once assembly is complete. That allows it to project through the hole provided in the laser-cut lid. But if you do so, insulate the wires with short pieces of heatshrink tubing or similar, keeping in mind that there can be around 100V between them during operation.

That completes the assembly of the shield board. Once this is done, double check your soldering. Given that the



This photo, along with the one opposite, shows how the three boards are "sandwiched" together – the Arduino Mega board on the bottom; the new shield board in the middle (green) and the 2.8-inch LCD touchscreen on top. It is designed to fit in a UB3 Jiffy box with a new laser-cut Acrylic lid. Note the connectors on the Mega board in the photo opposite – the USB on the left, and the DC power input at right.

board can generate over 100V, you don't want a small error on the PCB to feed that back into your computer. You may wish to use a USB Port Protector such as the one we described in May 2018 (siliconchip.com.au/Article/11065) a kit is available – Silicon Chip Online Shop Cat SC4574).

Unplug the shield/LCD assembly from the Arduino Mega now, as it's best to keep the boards separate until the Mega has been programmed, especially if the Mega has previously been programmed for another project.

Connect the Mega to a computer using an appropriate USB cable; most Megas have USB Type-B full-size sockets so you will need a Type-A to Type-B cable.

Installing the software

To install the software on the Mega, you need the Arduino IDE (integrated development environment) installed on your computer. The IDE includes a compiler and serial programming software, allowing the source code to be compiled and sent to the Arduino. The IDE can be downloaded from www.arduino.cc/en/Main/Software

We are using Arduino IDE version 1.8.5 but a newer version may be available by the time you check the download page.

Since we have written many of the libraries for this project ourselves, we have included all the necessary files in the sketch folder. Download the zip file from the Silicon Chip website and extract the contents to a suitable location such as your "Documents" or home folder.

Open the "Zener_Diode_Tester.ino" sketch file using the IDE. From the Tools menu, under Board, select "Arduino/Genuino Mega or Mega 2560". Then choose the appropriate serial port from the Tools -> Port menu. Click Upload or press Ctrl-U to start the compile and upload process. This may take a minute or two.

Unplug the USB cable and place the jumper shunt over the two pins of JP1 so that it is closed. Plug your shield PCB onto the Arduino Mega and then attach the LCD to the top of the PCB (if it isn't already attached). You are then ready for testing.

Testing and touchscreen calibration

Plug the USB cable back into the computer or if you have a 12V DC plugpack handy, use it instead. Ensure that the screen illuminates and displays the main menu page with the Silicon Chip logo. The Mega can have a start-up delay, so don't be alarmed if nothing happens for a few seconds.

The sketch is written with a default touch panel calibration. Try pressing some buttons on the touchscreen and check that they respond as expected. If you find that they don't, or the touchscreen calibration seems inaccurate, or it is not responding to touch at all, you will need to use our provided calibration sketch to calculate new touch panel calibration parameters.

By the way, we've seen some 2.8-inch touchscreens which look more or less identical to others but the touch panel axes are reversed. If you have one of those, you will definitely need to go through the calibration process.

To do this, open the "AVR_LCD_BackPack_Touch_

Parts list – Arduino-based Multi Diode Tester

1 double-sided PCB coded 04112181, 99mm x 60mm
1 Arduino Mega R3 board or equivalent [Jaycar XC4420, Altronics Z6241]
1 2.8-inch LCD touchscreen [Silicon Chip Online Shop Cat SC3820]
1 UB3 Jiffy box (included lid not required)
1 3mm laser cut Acrylic lid [Silicon Chip Online Shop Cat SC4927]
1 2-pin female header (CON1)
1 14-way female header (CON2)
1 2-pin header with jumper shunt (JP1)
1 6-pin, 2 8-pin & 1 10-pin header (to connect to Arduino)
1 2x3-pin female header (to connect to Arduino ICSP header)
1 100µH bobbin type inductor (L1)
1 DPDT relay with 5V DC coil and 250VAC-rated contacts, DIP-10 (RLY1)
1 12V 1A (or higher) plugpack with centre positive 2.1mm tip
2 M3 x 20mm Nylon panhead machine screws
3 M3 x 12mm tapped Nylon spacers
4 M3 x 10mm panhead machine screws
7 M3 x 6mm panhead machine screws
2 M3 Nylon hex nuts
2 M3 hex nuts

WARNING:
Do not touch any component leads while the unit is operating. 100V is enough to give you a bite!

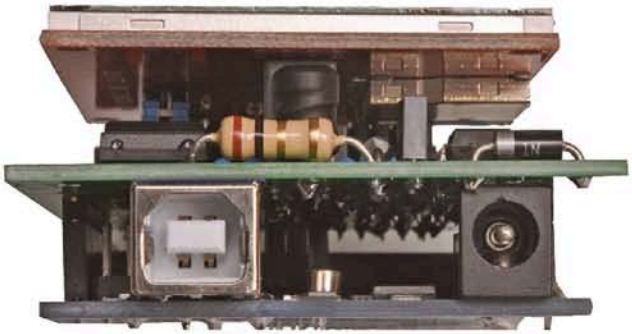
Semiconductors
1 1N4004 400V 1A diode (D1)
1 1N5819 schottky diode (D2)
1 LM358 op amp, DIP-8 (IC1)
1 LM311N high-speed comparator, DIP-8 (IC2)
2 PC817 optoisolators, DIP-4 (OPTO1,OPTO2)
1 IPA60R520E6 700V N-Channel Mosfet (Q1) [Silicon Chip Online Shop Cat SC3298]

Capacitors
1 100µF 10V electrolytic
1 1µF 450V electrolytic ***or*** 250V polyester "greencap"
3 100nF MKT or ceramic
2 10nF MKT or ceramic

Resistors (all 1/4W 1% unless otherwise stated)

2 1MΩ	2 100kΩ	2 36kΩ	2 30kΩ
1 13k	6 10kΩ	2 4.7kΩ	1 3kΩ
9 1kΩ	6 470Ω	1 100Ω	2 62Ω

1 1Ω 1W 5%



Calibration.ino" sketch and upload it to the Mega using the instructions above. Open the Serial Monitor from the Tools menu (or by pressing Ctrl-Shift-M) and set the baud rate to 115,200.

Following the instructions on the screen, use "1" (followed by Enter to send the command) to perform the calibrations. Then use "2" to test that the new calibration is accurate. Copy the new calibration constants from the Serial Monitor to the clipboard, as shown in Fig.3.

Now re-open the original "Zener_Diode_Tester.ino" sketch and open the "backpack.h" tab. Find the lines in the code which are shown in Fig.4. Replace the existing calibration constants with the new values you copied earlier, save the updated sketch and then upload it to the Mega. You are now ready for final testing.

Checking voltages and currents

Note as you read the following, that if you are using a computer USB port to power the unit during testing and calibration, some of the voltages mentioned below may not reach 100V and the unit may reset, due to the limited current capabilities of that port.

Start by clicking the Calibration button and use the Previous and Next buttons to scroll through the various items.

In the top-right corner, the display shows where to connect your multimeter test leads to read the appropriate voltage. The second line indicates the name of the value being tested. The third line indicates whether the test terminals should be open or short-circuited.

They should be short-circuited for the current test (eg, using your DMM in current measurement mode); otherwise, there is no path for the current to flow.

The first item to be checked is the output of the high-voltage generator, and this should be up around 100V, with an ADC value in the 900s. If this is the case, the high voltage system is working. If not, check (after powering off the unit) for wiring faults around the right-hand edge of the board, particularly around Q1 and L1.

The next three items measure the voltage at the positive test terminal with various gain settings. Using a DMM, measure the voltage at the positive terminal of CON1 (shown in Fig.2 and on the PCB) relative to TP3 (GND) and check that you get a reading that's close to the one shown on the screen.

The three following items are the negative test terminal voltage at its three different gain settings. Use the same technique as above to compare your readings to those shown on-screen. Any significant deviation in these voltages from reality indicates a problem in the vicinity of IC1.

The final item is the current reading, and as noted, it will only work if there is a path for the current between the test terminals. So switch your DMM to current meas-

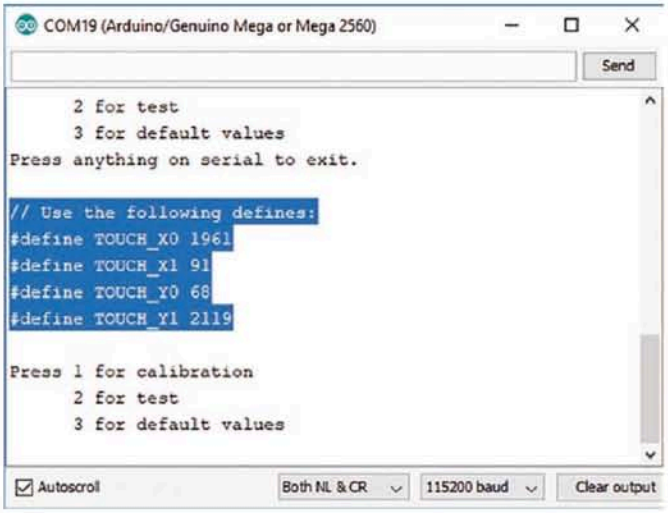


Fig.3: after running the touch calibration sketch and following the instructions, the highlighted text appears on the serial console.

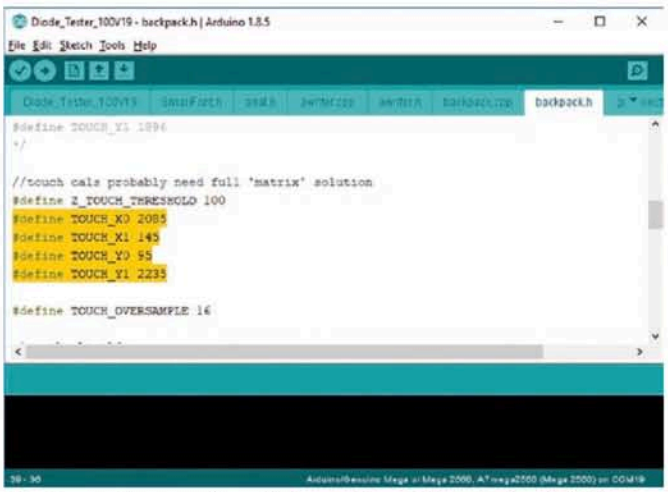


Fig.4: you then replace this portion of the main sketch with the text copied from Fig.3 above so that it uses the new touchscreen calibration.

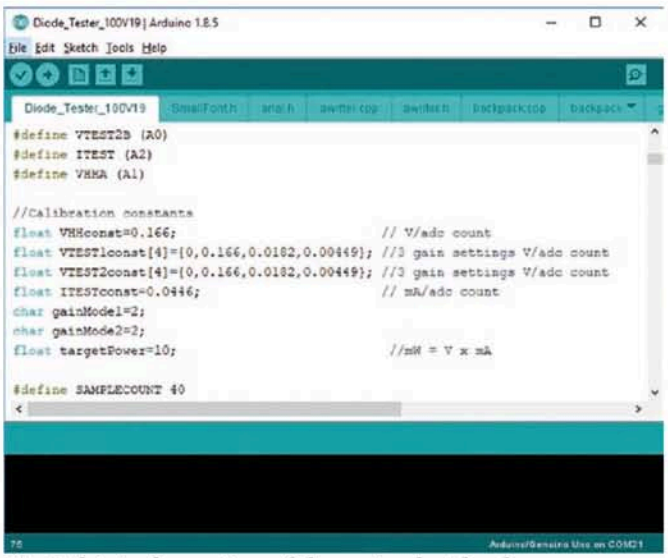


Fig.5: this is the section of the main sketch where you can change the calibration parameters, just below the comment reading "//Calibration constants"

urement (milliamps) mode and connect it across CON1. The displayed current should be around 30mA, with an ADC reading around 900. Compare this to the reading on your DMM. It should be close.

If you don't get any current reading or it is wildly off, then you may have a problem with the circuit around the optoisolators.

To calibrate the unit, step through each reading and record the ADC value shown and an accurate measurement of the voltage (or current) using your DMM. Then divide the voltage or current value by the ADC reading, and write this value down.

The unit is then calibrated by modifying the scaling values in the sketch itself. This part of the code is shown in Fig.5. It's near the top of the file. Find those lines and change the values to those you wrote down.

If the values you have are significantly different from the defaults, you may have a problem with your board, or you might have made a mistake in calculating these values.

Performing this calibration adjusts the software to be accurate with the particular components on your board (eg, the exact resistor values).

After the values have been edited, the sketch will need to be uploaded again, as per the earlier instructions, to allow the new values to take effect.

Completing assembly

Once you are satisfied that the unit is calibrated and working correctly, it can be fitted in its case. Start by removing the screws holding the LCD screen onto the tapped spacers, then temporarily unplug the screen.

Now plug the shield into the Arduino Mega and secure the two together using the specified Nylon machine screws and nuts, through the mounting holes near Q1 (adjacent to the Arduino SCL pin) and near the Arduino A5 pin.

Next plug the LCD back into the shield but don't attach it using screws just yet. Slot the laser-cut lid panel over the LCD screen, then feed 10mm machine screws through the panel and LCD, into the three tapped spacers below.

Use the fourth 10mm machine screw and single nut to hold the lid onto the LCD screen using the remaining mounting hole, in the upper-right corner.

If you aren't planning to read measurement data out to a computer via the serial port and you are using the a plugpack supply, then you only need to make a hole in the box base for the DC power jack. Otherwise, you will also need to make a cut-out to access the USB socket.

Make the holes in the lower half of the UB3 case as using the drilling diagram (downloadable from siliconchip.com.au) as a guide. Finally, attach the lid to the top of the box using the supplied self-tapping screws.

Using it

This device will test just about any type of diode including standard silicon diodes, schottky diodes, LEDs and unidirectional or bidirectional transient voltage suppressors.

Having connected the device to both of the test terminals, press the I/V Test button on the screen.

You should hear two clicks and the graph will be displayed. If you have inserted the component backwards, press Reverse to swap the plot around.

You can also touch the graph on the touchscreen to display figures for various voltages and currents. Cursors appear to show the point being touched and the relevant information is displayed in a second box on the bottom left of the screen.

Pressing Back returns to the main menu page. From there, press the LED Test button to start the LED test.

The voltage and current limits are set using arrow buttons at the bottom of the screen. These are soft limits which are controlled by the microcontroller, so the readings may occasionally drift above these settings. If this occurs, a small red asterisk is shown to alert you to that fact.

The high voltage rail value is shown at the bottom of the screen, and the current device operating conditions are shown along the right-hand side of the screen.

Press Back again and then press Settings to go to the settings page. This sets the various parameters for the I/V Test mode (the LED test mode has its settings shown on that screen, as explained above). The Previous and Next buttons scroll between various items, while the Up and Down buttons change the values of those items.

There are seven settings available. The first allows you to select either a 400mW or 1W zener; it automatically sets the maximum and target power settings. If this is set to "Manual" instead, the next two items can be used to set the maximum and target power manually.

The following two items allow you to manually set a conservative current and voltage limit for I/V tests. When running I/V tests, the test is stopped if either of these limits is exceeded.

The final two items set the scale of the graph. If, for example, the voltage scale is set to 10V, then the horizontal axis of the graph will span -10V to 10V.

Any time the "Back" button is pressed from the Settings page, the settings are saved to EEPROM. The program uses a clever update method so that EEPROM is not rewritten unless necessary, so going into the Settings menu and then exiting without making any changes will not cause any wear on the EEPROM.

In any case, the EEPROM is rated for at least one million rewrites per cell, so you would have to spend a very long time making changes before you're likely to run into any problems with the EEPROM! SC

Resistor Colour Codes

Qty.	Value	4-Band Code (1%)	5-Band Code (1%)
❑ 2	1MΩ	brown black green brown	brown black black yellow brown
❑ 2	100kΩ	brown black yellow brown	brown black black orange brown
❑ 2	36kΩ	orange blue orange brown	orange blue black red brown
❑ 2	30kΩ	orange black orange brown	orange black black red brown
❑ 1	13kΩ	brown orange orange brown	brown orange black red brown
❑ 6	10kΩ	brown black orange brown	brown black black red brown
❑ 2	4.7kΩ	yellow violet red brown	yellow violet black brown brown
❑ 1	3.0kΩ	orange black red brown	orange black black brown brown
❑ 9	1kΩ	brown black red brown	brown black black brown brown
❑ 6	470Ω	yellow violet brown brown	yellow violet black black brown
❑ 1	100Ω	brown black brown brown	brown black black black brown
❑ 2	62Ω	blue red black brown	blue red black gold brown
❑ 1	1.0Ω (1W, 5%)	brown black gold gold	

"Hands On" review by Tim Blythman

NEW FROM ARDUINO MKR VIDOR 4000

This newest Arduino FPGA board sports a 48MHz 32-bit processor with 256KB flash and 32KB RAM, extra flash and RAM, onboard WiFi and Bluetooth, HDMI video output and camera interface connectors, a battery charge controller, cryptography chip and a large field programmable gate array (FPGA). It can be plugged directly into a breadboard for experimentation.

Arduino boards are very popular and have spawned many clones and copies. There is no doubting the attractiveness of the ATmega328-based Uno and its other 8-bit relatives such as the Mega and Nano (both described in the December 2018 issue; see siliconchip.com.au/Article/11335).

But the Arduino company has not stood still and they continue to release even more powerful boards.

The Arduino MKR Vidor 4000 is their latest product. They have released quite a few boards since the Uno, but none have reached the same level of popularity.

Many of the newer boards, such as the Due, now use 32-bit ARM processor rather than the 8-bit AVR chip, and the MKR (short for "maker") series of boards have also changed to a more compact, breadboard friendly pin layout. These new chips have a 3.3V maximum supply voltage and have 3.3V I/O levels, compared to a typical 5V for the AVRs.

The newer boards have many extra features compared to the Uno/Nano/Mega, especially for wireless communications, as it is expected that these development boards will be used in "IoT" (Internet of Things) type applications.

Vidor details

The Vidor's main processor is a Microchip ATSAMD21 (ARM Cortex-M0+ processor), with 256kB of FLASH memory and 32kB of SRAM. It operates at 48MHz and has 22 I/O pins. As mentioned above, these I/Os have a 3.3V swing.

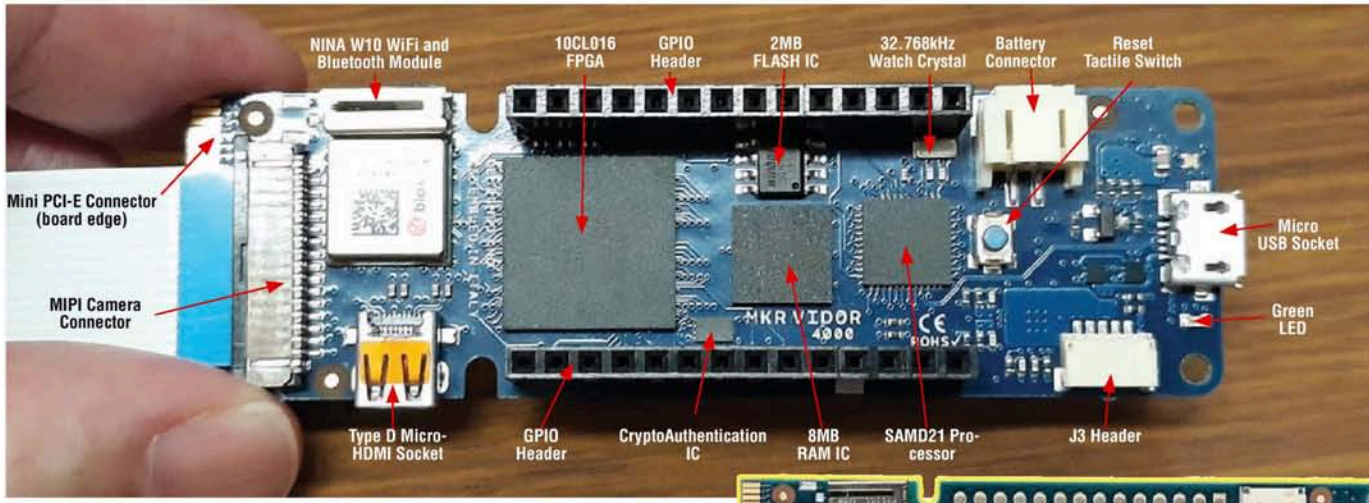
It has 12 pulse-width modulation (PWM) outputs, seven inputs to the analog-to-digital converter (ADC) and a single 10-bit digital-to-analog converter (DAC) which can be routed to a specific pin. It can also operate as a USB device or host.

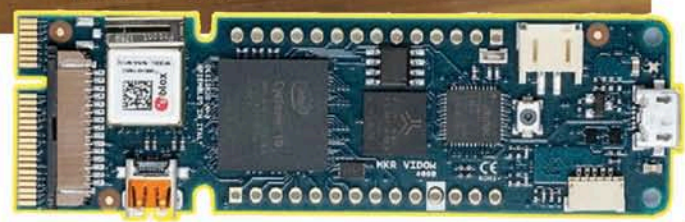
There's also an 8MB RAM chip and 2MB flash memory chip on the board, in addition to the central processor's internal memory.

The Vidor includes a U-BLOX NINA W10 WiFi/Bluetooth module. This is a variant of the ESP32 IC, the bigger brother of the ESP8266 (described in the April 2018 issue; see siliconchip.com.au/Article/11042). This contains an embedded 32-bit microcontroller which could, on its own, be programmed by the Arduino IDE.

The same WiFi/Bluetooth module also appears on the new Uno WiFi Rev2 board, released around the same time as the MKR Vidor 4000.

The Uno WiFi Rev2 retains the clas-





Like many recent Arduino boards (and unlike the early ones), it's built almost entirely from surface-mount devices. This view shows the top side of the PCB and identifies major components. Both of these labelled photos are shown significantly over size (for clarity – actual PCB size is only 83 x 23mm, as shown inset at right).

sic Uno form factor but uses the slightly more powerful ATmega4809 8-bit processor. That would be a good one to use if you are familiar with the Uno and need the WiFi feature but not any of the other features of the Vidor.

Helpfully, the Vidor pin numbers are printed on the side of the headers, including alternative pin functions (eg, SPI and I^2C) as appropriate. This is necessary because there is little room on the top of the PCB itself for pin designations.

Most of the pin designations are also printed on the underside of the board.

The main components of the board are highlighted in the adjacent photos. Items of note include the TI BQ24195L-RGET battery charger IC and the Microchip ATECC508A Crypto-authentication IC. The ATECC508A provides hardware acceleration of AES and other secure network connections such as TLS, and is connected to the micro via an I^2C bus.

The battery charger IC connects to the USB port and can detect the USB host's charging capability. The IC also connects to the ATSAMD21's I^2C bus for charge control and monitoring.

The underside of the board also sports two unpopulated headers. There is a space for a six-pin 0.1-inch pitch header and a ten-pin 0.05-inch pitch header.

Both of these sets of pads are routed to the ATSAMD21, for access to the Serial Wire Debug (SWD) and JTAG debugging/programming interfaces.

Onboard FPGA

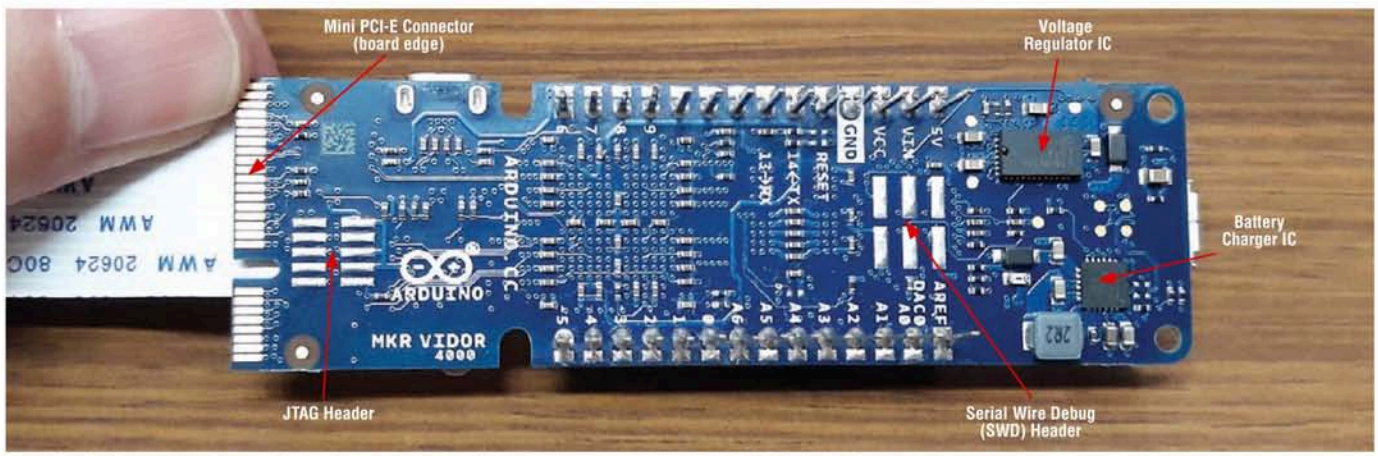
But the most unusual feature of this Arduino board is that it incorporates an Intel Cyclone 10CL016 FPGA. The FPGA is hooked up to most of the board I/O pins, as well as the micro HDMI socket and the MIPI camera connector.

This FPGA gives the MKR Vidor 4000 capabilities beyond a plain microcontroller, but perhaps not quite as advanced as a fully-fledged computer.

A Field Programmable Gate Array is an array of logic gates (like practically any logic IC or even microcontroller) which is programmable after it has left the factory (ie, "in the field").

Being an array of gates, in effect, everything on an FPGA happens in parallel, rather than in a serial, one-at-a-time fashion as is the case with microcontrollers.

This means that FPGAs are great for digital signal processing, such as audio and video compression/decompression, and even AI-like tasks such as image recognition.



Similarly, here is the underside of the board with maor components identified.

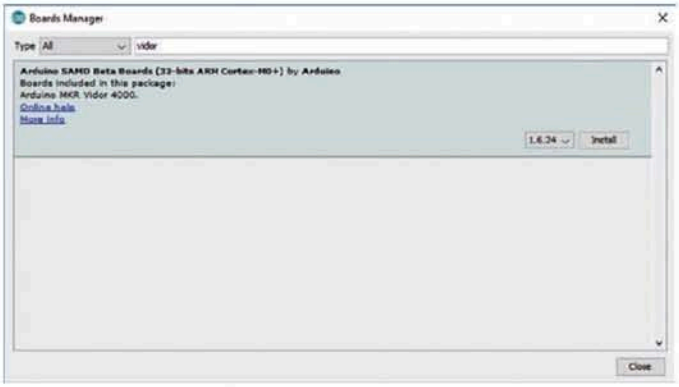


Fig.1: the board profile for the Arduino MKR Vidor 4000 can be found by searching for "vidor" in the Arduino IDE's Boards Manager window.

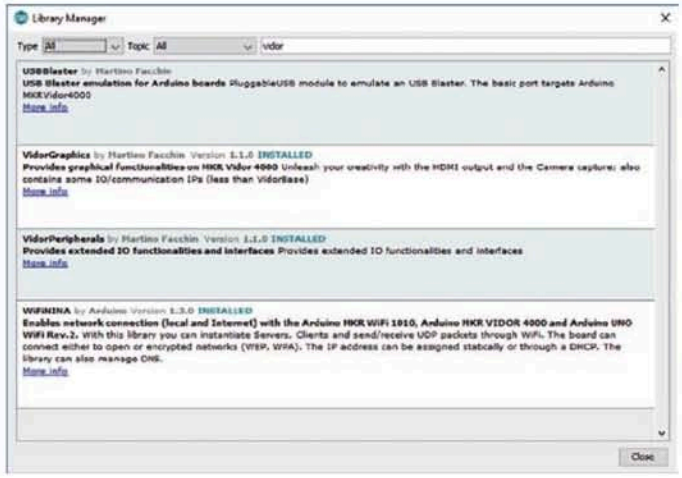


Fig.2: we recommend installing these three libraries to use with the MKR Vidor 4000. There don't appear to be any third-party libraries specific to the Vidor just yet.

In theory, given enough internal gates, an FPGA can provide the functionality of just about any digital IC, and in fact, FPGAs are often used in the design stage of ASICs (application specific integrated circuits), including some CPUs, to test the design before the final chips have been manufactured.

What that means in practice is that the FPGA can be reprogrammed to provide different hardware functions depending on what is needed for the project at hand.

In terms of complexity, programming an FPGA is a step above programming a microcontroller. But with the Vidor 4000, you don't usually need to worry about that.

The Arduino integrated development environment (IDE) contains pre-compiled FPGA software or "IP blocks" which are loaded into the flash memory during the upload process. Just like libraries, they provide functions that can be controlled from the Arduino program but do not need to be understood at a deep level.

Out of the box, the FPGA provides access to the HDMI and camera features on the board, amongst others. But what the FPGA adds in broad terms is peripherals.

It is possible to use the FPGA to access extra PWM, I^2C, SPI and UART channels, and these peripherals can be configured to operate on any I/O pin.

At the moment, Arduino libraries for the MKR Vidor 4000 may configure the FPGA, splitting some of the tasks between the main processor and the FPGA.

While the concept of IP blocks does not sound like it is consistent with the open-source ethos that the Arduino software is known for, the process for creating IP blocks is open-source. However, as yet, few people are creating open-source IP blocks.

We understand that soon it will be possible to create more features for the FPGA using a web interface and cloud-based compiler, although this will likely be in a very different language to the usual Arduino IDE.

It is expected that contributed IP blocks will greatly expand the usefulness of the MKR Vidor 4000.

Information about creating IP blocks can be found at: https://github.com/vidor-libraries/VidorBitstream

Getting hold of a Vidor board

Before we could try the Vidor out, first we actually had to get one, which turned out to be a bit harder than expected.

When we ordered our MKR Vidor 4000 board from element14, we were required to complete an import declaration, stating that we would not re-export the unit, nor use it in chemical, biological or nuclear weapons and that the unit would not be supplied to a military end user.

Unfortunately, this meant that we had to put aside our plans for world domination.

Having completed the declaration, we received the unit not long after. Besides the board itself, we got a small sheet of Arduino stickers in the box and a product guide with warranty and RoHS-compliance information.

If you are familiar with the Uno, the first thing that will strike you is how small the Vidor is. It's about half the size of the Uno and is fitted with two rows of stackable headers. We attached the unit to a 400-hole breadboard to avoid damaging the pins underneath.

Software

As with other Arduinos, to program the MKR Vidor 4000, you need the Arduino IDE software. This includes a code editor, compiler and upload tools.

Although there is some basic example code available for the MKR Vidor 4000, we would suggest some experience with a simpler board (such as an Uno) before trying to work with the MKR Vidor 4000.

We are currently using Arduino IDE version 1.8.5, which appears to be the same version as shown in many of the MKR Vidor 4000 examples.

Although no version number is given as a minimum requirement for working with the Vidor, you need version 1.6.4 or later to use the Boards Manager tool (which we highly recommend for ease of use).

The IDE can be downloaded from www.arduino.cc/en/Main/Software but there is also an online-only version of the IDE which you can access at https://create.arduino.cc/ (you need to create an account on that website before you can use it).

Once the IDE is installed, the MKR Vidor 4000 Board Profile needs to be installed. The Boards Manager (found under the Tools → Board → Boards Manager... menu) is the easiest way to do this.

Inside the Boards Manager, search for "vidor" (see Fig.1), click on the

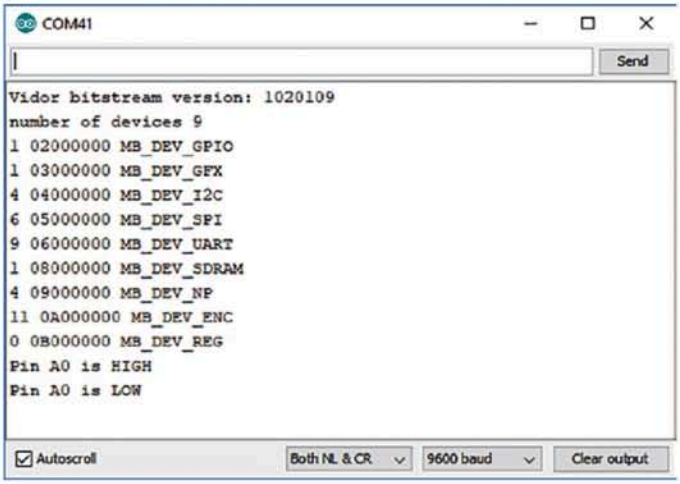


Fig.3: this shows the output of "VidorTestSketch". It lists which IP Blocks are currently loaded into the FPGA. The list includes support for numerous peripherals.

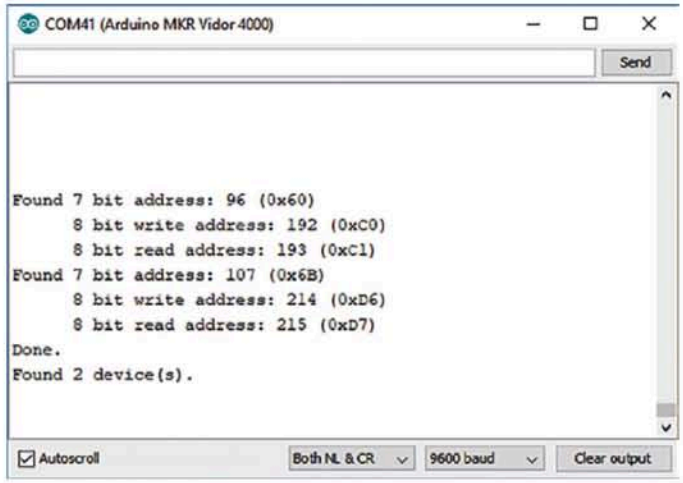


Fig.4: an I²C scanner sketch shows two devices on the board that are pre-connected to the I²C bus. These are the Crypto-authentication IC (0x60) and battery charge IC (0x6b).

option shown and click install. This can take a while, as the entire SAMD21 toolchain needs to be installed.

Under Windows, this also installs the MKR Vidor 4000's USB drivers. For macOS and Linux, no drivers are needed.

Once the Board Profile is installed, we recommend adding some of the Vidor-specific libraries as well.

These can be installed using the Library Manager (found under Sketch → Include Library → Manage Libraries...). Again, simply search for "vidor".

We suggest you install the Vidor-Peripherals, VidorGraphics, and WiFiNINA libraries – see Fig.2. The USBBlaster library is a tool used for updating the FPGA if you are developing your own IP Blocks, and is otherwise not needed.

Adding some extra hardware

We're intrigued by what can be achieved by adding a camera to an Arduino board, but there isn't much information about what cameras will work, except that camera needs to plug into the board's "MIPI" connector.

Since this connection appears to be the same as the commonly available Raspberry Pi cameras; we tried one and it worked fine. The camera we used has "Rev 1.3" printed on it.

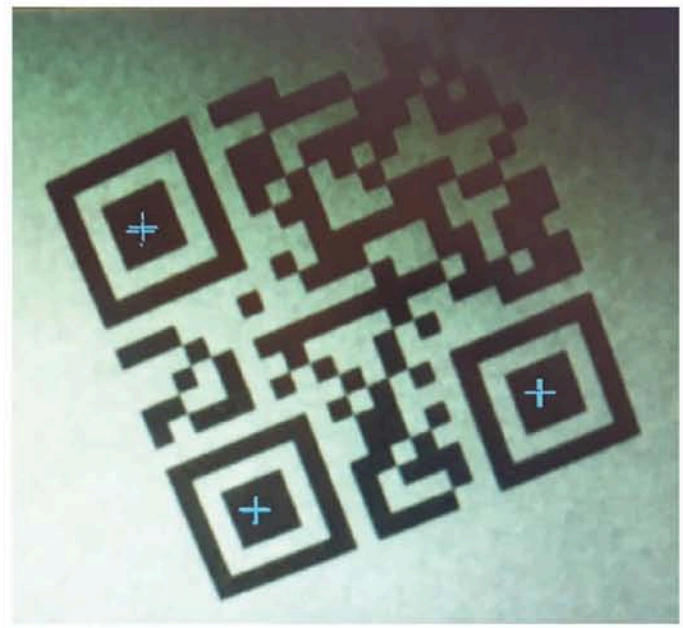
These flexible flat cables (FFC) can be fiddly to plug in. Ensure that the contacts on the camera cable face down (towards the Vidor PCB), push the cable in as far as possible and then squeeze the black and brown halves of the connector together.

The Vidor also has a Micro-HDMI (type D) socket, so to connect to a monitor, you will need a Micro-HDMI to full-size HDMI adapter, or a suitable cable.

What can it do?

Now let's look at what we can do with all this extra hardware. There are a few example sketches that are installed along with the aforementioned libraries. The WiFi examples are numerous, but we won't delve into these; the WiFi capabilities of this board are similar to many other boards.

In fact, given that the WiFi function is supplied by an ESP32 compatible module, the capabilities and interface will be practically identical to the ESP32 based boards that can



Above: the output of the "VidorDrawLogo" sketch on an HDMI monitor. The display has a resolution of 640 x 480. Right: the "VidorQrRecognition" sketch can identify and mark, but not decode, QR codes.

be programmed by the Arduino IDE. There are six distinct examples provided within the two main Vidor libraries. The examples can be found under File → Examples → VidorGraphics and File → Examples → VidorPeripherals. They only appear when "Arduino MKR Vidor 4000" is selected in the Tools → Board menu.

You may need to scroll down if you have a lot of libraries or boards installed.

Having loaded an example sketch, select the correct serial port from the Tools → Serial Port menu and then press Ctrl-U to compile it and upload it to the Vidor board.

One thing we found with the examples is that they all include the line:

```
while (!Serial);
```

This means that the Serial Monitor needs to be opened before the program will proceed. For these examples, it worth having the Serial Monitor open to watch the sketch report what it's doing, but we were surprised to see the basic HDMI example fail to output video just because we had not opened the Serial Monitor yet.

We tried the "VidorDrawLogo" example first. It displays the Arduino logo displayed on an attached HDMI monitor.

Interestingly, a much clearer version of the logo can be seen for about a second before this; it appears that the Vidor has its own splash screen built in, too.

While hardly extraordinary, this is a great example of how simple it is to drive an HDMI monitor.

If you have previously used any graphics type displays with the Arduino IDE, the drawing commands will be familiar. Although basic, we expect people will use this feature to create video games.

We tried the "VidorEnableCam" sketch next. It takes the video stream from the camera and displays it on the HDMI monitor.

Next, we tried the "VidorQrRecognition" sketch. We found a QR code and held it in front of the camera. The result is seen in the adjacent photo.

It appears that this sketch will detect a QR code, but not decode it. The three marker points are found and flagged with a cross, but the code does not have any means of decoding QR codes.

This would be a handy tool for an Arduino board to have (being able to read linear barcodes would also be useful), but it seems to be just a proof-of-concept.

Still, the ability to overlay graphics over a camera stream raises some exciting possibilities for video processing.

We did not try the "VidorNeoPixelMatrix" (for driving serially addressable RGB NeoPixels) or "VidorEncoder" (for reading quadrature encoders) examples, but the intent of these demos is clear.

Both these tasks require very tight timing considerations to work correctly.

By offloading these duties to the FPGA, the main processor can focus on doing what it needs to do, but without needing to deal with time-critical peripherals directly.

The final example is named "VidorTestSketch". It demonstrates using both the central processor and FPGA to control the I/O pins and shows some information about the IP blocks in the FPGA – see Fig.3.

Further experiments

While the "VidorQrRecognition" example shows that it is possible to process video data with the MKR Vidor 4000, inspection of the source code shows that there is no easy way to access the contents of the camera video stream.

The video processing is done using the FPGA and so is hidden in the IP Block.

While it's possible to lay graphics over the camera stream using regular Arduino code, manipulating and interacting with the video appears to be out of reach at the time of writing.

One example of the potential use of such processing would be to perform chroma key processing of video.

Also known as "green screen" or "blue screen", this involves replacing the colour-coded background of a video stream with a different image. For pixels that match the key colour (ie, blue or green, depending on the implementation), the background image or video is shown instead.

You would be familiar with this effect from its widespread use in TV weather broadcasts.

If we could read the contents of the camera stream, then it would be a simple case of checking each pixel and displaying the foreground or background as appropriate.

This would actually be an ideal task for the FPGA, and we may see a future IP Block providing this feature.

On the bus

We also noted that the battery charge IC and crypto-authentication IC are connected to the I^2C bus of the ATSAMD21. We ran an I^2C scanner sketch to see if there were any other devices. The results are shown in Fig.3. According to the datasheets, the device at 0x6B is the battery charge IC, and the device at 0x60 is the Crypto-authentication IC.

The specs of the battery charge IC indicate that it is a switchmode device operating at 1.5MHz with an adjustable charge current of up to 2.5A and efficiency up to 92%.

It can operate from 5V USB power or 3.9-17V DC.

It also provides a boost regulator which can be used to provide a 5V rail from a single-cell lithium-ion battery and a host of other charge management and power management features.

Verdict

The Arduino MKR Vidor 4000 looks like it's a very capable device but it's a pity that so much of its power is locked up in the "black box" of the FPGA IP Blocks.

This means that the examples provided don't really demonstrate what it is capable of. Having said that, being able to draw reasonably high resolution (for an Arduino) graphics to an HDMI display is an excellent feature in its own right.

We expect that as more people develop IP Blocks, we will see some great applications for the Vidor.

An FPGA is well suited for highly parallel tasks such as image recognition and it will be interesting to have such a feature available on something smaller than a fully-fledged computer or small-board computer (SBC) like the Raspberry Pi.

Just as the multitude of third-party libraries has made the Arduino ecosystem so flexible, we hope that the community will create some great libraries for the FPGA side of this board as well.

The Arduino MKR Vidor 4000 is available from Mouser Electronics with free delivery.

See: https://au.mouser.com/new/arduino/arduino-mkr-vidor-4000/ and https://au.mouser.com/ProductDetail/Arduino/ABX00022

SC

Building our new Trailing Edge Dimmer

Part II
by John Clarke

for modern mains-powered lighting

Last month, we described how our new trailing edge dimmer can drive dimmable LEDs and compact fluorescent lamps, as well as incandescent and halogen lamps using suitable transformers, where an old-style leading-edge dimmer can not. It's an elegant and modern-looking design which can be controlled using one or more touch panels, or a slimline infrared remote control. Now we move onto building it and wiring it up.

In the first article (February 2019 Silicon Chip), we explained why you need a trailing edge dimmer to control modern LED lighting.

Older dimmers used Triacs and this necessitated switching power to the lamp(s) on in the middle of a mains half-cycle and off at the zero crossing.

But that's no good for devices that use switchmode supplies, such as LEDs, CFLs and halogen lamps with electronic transformers. It generates very high current spikes that will quickly destroy the power supplies

This trailing edge dimmer does not have that problem, and many modern lights are now designed to be dimmed by just this type of device.

While we had an extensive explanation of leading vs trailing edge dimmers last month, we didn't have room to show actual scope grabs of these dimmers in operation. Now we do, so you can refer to Scope1-Scope5.

Scope1 shows an older style leading edge dimmer operating with an incandescent lamp load. Scope2 shows the same type of dimmer attempting to drive a dimmable LED. You can see that it doesn't work very well!

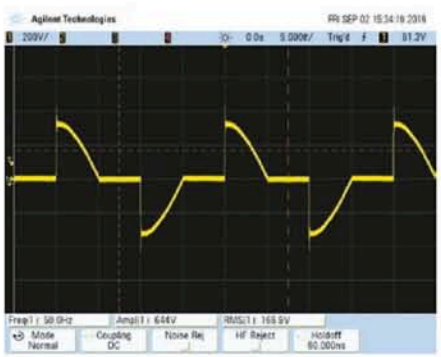
In contrast, screen grabs Scope3-Scope5 show the waveforms applied to a dimmable LED lamp from a trailing edge dimmer. You can see that these waveforms are pretty clean and the lamp's brightness varied as you would expect, from a low level when Scope3 was taken up to moderately high brightness for Scope5.

So now that you know how this Dimmer works and you've read about all its great features, naturally you want to build one (or several).

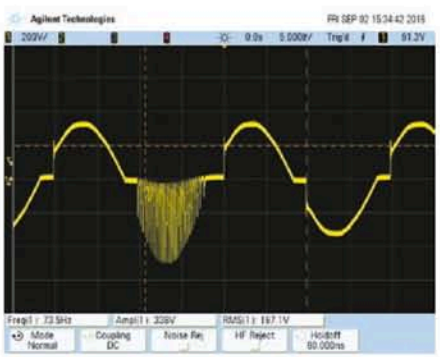
You can purchase the PCBs and hard-to-get parts from the Silicon Chip Online Shop (see parts list last month), and the remaining parts from your usual component supplier(s). You can then begin to put the boards together, using the following instructions.

Is it legal to build?

Before we get into it, note that while you can certainly build this dimmer yourself (and we've gone to quite a bit of effort to make it as simple as possible), in Australia it is not legal to wire



Scope1: an incandescent lamp dimmed to half brightness using an old-fashioned leading-edge dimmer. You can see how the lamp voltage suddenly jumps from near zero up to the full ~325V DC mains peak voltage when the Triac turns on. That would cause a huge inrush current with a typical LED lamp which has a capacitor-input switchmode power supply. It would probably destroy the lamp in a short time; even if it didn't, it would likely flash like a strobe.



Scope2: here's a LED lamp being powered from a leading-edge dimmer set near full brightness. This is an example of what not to do! You can see that even though the voltage steps are not quite as severe in this example as in Scope1, the lamp still "wigs out" during the second half-cycle, switching on and off rapidly and drawing high current pulses. Its electronics won't last long operating under these conditions.

The three assembled PCBs used in this project. On the left is the main board which contains the PIC – which controls everything – along with the transformer (which you wind yourself) and the power Mosfets plus, of course, the connection terminal block (the opposite side of this PCB is not shown). In the middle is the mounting plate which maintains electrical isolation, while on the right is the optional dimmer extension (which you only require if you need extra touch plates).

it up yourself. You will need a licensed electrician to do so.

If you're lucky enough to live in New Zealand, though, you can do your own household wiring legally so we have shown the appropriate wiring diagrams.

Construction

The dimmer is built on a PCB coded 10111191, measuring 66 x 104mm. The PCB assembly mounts on a separate Backing Plate PCB coded 10111192 which measures 58.5 x 104mm and the whole assembly mounts within a Clipsal Classic blank plate, with a matching blank aluminium touch plate.

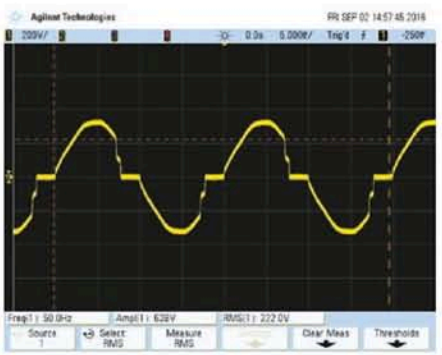
The completed dimmer can be mounted to a metal wall box in a brick wall, but it must be spaced from the wall box using a mounting block of 30mm or deeper; otherwise, the circuit may make contact with the metal box, which would be a hazard.

It can be mounted directly to a stud on a plasterboard wall using standard mounting hardware. Alternatively, it can be placed on a thin or standard depth surface-mounting box.

Refer to the PCB overlay diagram, Fig.3, during assembly. Fig.4 shows what the more-or-less blank mount-

Scope3: this is how you should dim a LED lamp. In this case, it is being driven by a trailing-edge dimmer at a low brightness level. Here the lamp voltage smoothly ramps up from zero to just under 200V, then the transistor switches off power to the lamp until the start of the next half-cycle. The lamp detects the reduced duty cycle/ peak voltage and runs at reduced brightness.

Scope4: the same LED lamp being run from the same trailing-edge dimmer but with a slightly increased brightness level. The step that you can see is probably because the capacitors in the lamp's switchmode supply remain charged after the transistor in the dimmer has switched off, and a small amount of voltage feeds back into the scope through the bridge rectifier.



Scope5: here, the LED lamp is operating at around 75-80% of full brightness. You can see that the dimmer transistors remain switched on for more than half of each mains half-cycle. Comparing this to Scope2, it is obvious that a dimmable LED lamp operates in a much smoother manner with the trailing edge dimmer than it did with the traditional leading edge dimmer.

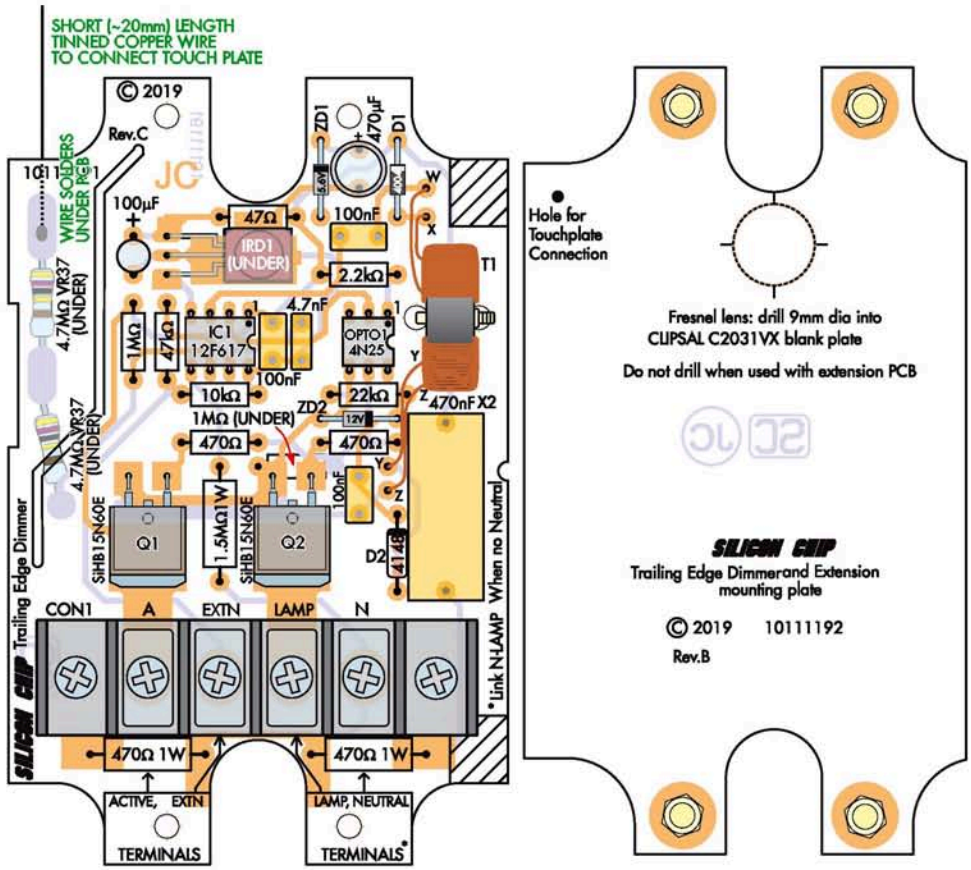


Fig.3: the PCB overlay diagram for the main Dimmer board, which you can use as a guide during construction. The infrared receiver IRD1 and three resistors (one 1MΩ and two 4.7MΩ) are mounted on the underside of the board (not shown separately). These resistors are mounted on the PCB surface (ie, not through holes), despite being axial leaded components. Mosfets Q1 & Q2 are SMDs and they are soldered to the top of the board. Also note the short length of tinned copper wire soldered to the underside of the PCB – it bends out 90° (ie, away from the PCB) to pass through the hole in the second board and thence through a hole drilled in the Clipsal mounting plate, to make contact with the touch plate.

The second board (Fig.4, shown at right) does not have any components on it but has four nuts soldered to the top of the board to secure the main (or extension) PCB to.

ing plate PCB looks like.

For assembling the main PCB, start by fitting Mosfets Q1 and Q2. These are surface-mount devices which are soldered to the top side of the PCB. The substantial metal tabs need to be soldered using a hot soldering iron.

It helps to spread a little flux paste on the tab pad before soldering the two smaller leads in place, then finish by soldering the tab. Make sure you heat the tab long enough for the solder to flow properly onto both the Mosfet tab and PCB pad, forming a nice, smooth fillet.

You can then install the axial devices – ie, resistors, zener diodes and diodes. The Resistor Colour Codes table shows the codes but it is a good idea to use a digital multimeter to measure each value before soldering, just to make sure. (Many resistor colour bands can be mistaken, especially in low light).

Note the specifically-called-for resistors in the table – the 4.7MΩ must be the type shown and no codes are given for the 1W resistors in 5-band as these are very uncommon.

Leave off the 4.7MΩ and 1MΩ resistors for now, as they are mounted on the underside of the PCB later.

Diodes D1 and D2 can be easily distinguished as D2 is much smaller than D1 but ZD1 and ZD2 may look similar, so be careful to install the 5.6V and 12V zeners in the locations shown in Fig.3.

Fit the microcontroller and optocoupler next. Ideally, IC1 should be mounted using a socket, to make it easier to re-program if necessary, while OPTO1 should be soldered directly to the PCB. Be sure to orientate both correctly, with the pin 1 notch or dot located as shown in the overlay diagram, before soldering them.

The capacitors can be installed now, starting with the smaller MKTs, then the larger X2 capacitor and finally, the electrolytic capacitors.

Only the electrolytic capacitors

Parts missing from the parts list last month

2 M3 x 15mm panhead machine screws
2 M3 nuts
(for both the main and extension PCBs)

Resistor Colour Codes

	Qty.	Value	4-Band Code (1%)	5-Band Code (1%)
❑	2	4.7MΩ	yellow violet green brown	*(must be VR37 3.5kV safety resistors)*
❑	1	1.5MΩ 1W	brown green green brown	(n/a)
❑	2	1MΩ	brown black green brown	brown black black yellow brown
❑	1	47kΩ	yellow violet orange brown	yellow violet black red brown
❑	1	22kΩ	red red orange brown	red red black red brown
❑	1	10kΩ	brown black orange brown	brown black black red brown
❑	1	2.2kΩ	red red red brown	red red black brown brown
❑	2	470Ω 1W	yellow violet brown brown	(n/a)
❑	2	470Ω	yellow violet brown brown	yellow violet black black brown
❑	1	47Ω	yellow violet black brown	yellow violet black gold brown
For the Extension Board:				
❑	2	4.7MΩ	yellow violet green brown	*(must be VR37 3.5kV safety resistors)*
❑	1	2.2MΩ	red red green brown	red red black yellow brown
❑	1	1MΩ	brown black green brown	brown black black yellow brown
❑	1	220Ω	red red brown brown	red red black black brown

(100µF and 470µF) are polarised; their longer leads go into the pads marked with a + symbol in Fig.3 and on the PCB silkscreen printing.

Next, mount the large four-way terminal barrier. Attach it to the PCB using two M3 panhead machine screws, approximately 20mm long, and two M3 hex nuts (which were not included in the parts list published last month). Once it's securely fastened to the board, solder the four terminals using plenty of solder, to ensure reliable connections.

Next, assuming you want infrared remote control, file the uppermost sharp corners of the infrared receiver plastic package so it fits inside the fresnel lens. The infrared receiver is mounted flat to the underside of the PCB with the lens located along the vertical centre line of the PCB. The PCB screen printing shows the correct mounting position.

Bend its leads at right angles and feed them through the PCB pads, then solder them on the top side. If you do not want to use the infrared remote control option, instead you should fit a 1kΩ resistor between the outer two mounting pads for IRD1.

Winding transformer T1

T1 is made up using a toroid ferrite core and windings made from 0.25mm diameter enamelled copper wire (ECW). The primary winding consists of 12 turns while the secondary has 48 turns, as shown in Fig.5.

The primary and secondary are separate windings that are wound on opposite sides on the toroid, for isolation.

Twist the two primary winding end wires together with a few turns and do the same to the secondary wire ends (this is not shown in Fig.5 for clarity). Cut off any excess wire length, ensuring there is enough left to reach the PCB pads, then use emery paper or a hobby knife to strip off the enamel insulation from the ends of each wire, so you can tin them. Make sure the solder takes properly to the wire.

Can this dimmer be used with a standard lamp, etc?

We've already been asked (!) . . . what if you have a lamp that's normally plugged in (ie, such as a standard lamp, desk lamp, etc – one not "wired in" to the house wiring)? Is this dimmer suitable for these types of lamps?

The beauty of this dimmer circuit is that it suits so many types of globes, (incandescent, dimmable LED, dimmable CFL, and so on) so in the vast majority of cases would be perfect.

Of course, you would need to make absolutely certain that any box used was 100% insulated and, if metal, Earthed.

The procedure we show in Fig.8 for testing the dimmer with an available Neutral is precisely how you would wire the dimmer for "plug in" use.

If your lamp is currently being powered by a two core cable (ie, Active and Neutral) the cable should be replaced with a three-core (Active, Neutral and Earth).

Now attach two cable ties to the ferrite core and do them up tightly before cutting off the excess length, to ensure that the two windings stay separate.

Next, cut a length of 16mm diameter heatshrink tubing that's longer than the ferrite core is wide, slip it over the core with the primary winding exposed at one end and the secondary at the other, and shrink it down so it won't move.

Once you've done that, cut or punch some holes at the bottom to allow a cable tie to pass through. You can do this using a screwdriver but be careful not to damage the core or any of the windings when doing so.

Mounting T1

Feed a cable tie through the holes you made in the heatshrink tubing and then loop it through the 3mm holes in the PCB which are designed to hold the transformer in place. The square end of the cable tie should be kept on top of the PCB, on one side of the toroidal core. The PCB will not mount correctly if the end of the cable tie is on the underside of the PCB.

Solder the two ends of the primary winding to the pads labelled W and X; it doesn't matter which one goes to which. Similarly, solder the ends of the secondary to the pads labelled Y and Z.

Now you can fit the three resistors that go on the underside of the board. The 1MΩ resistor has a hole for one of its leads and a pad for the other, but both are soldered on the bottom side of the board. Make sure you trim the lead which pokes through the top side short after soldering it.

Connection to the touch plate

The soldering on the two Vishay 4.7MΩ VR37 series resistors is critical. Bend and cut their leads so that they sit flat on the provided circular pads and then solder them in place, surface-mount style.

Make sure they are placed in the correct position and *do not substitute anything else* for these components. These resistors, chosen specifically for safety, are light blue in colour and are rated at 2.5kV RMS.

They are fitted like this so that no connections are exposed on the top of the PCB. That fully isolates the resistor leads from the components on the top of the PCB.

Also, it provides a high degree of voltage isolation between the touch plate connection and high voltage circuitry.

The series resistors actually make contact with the touch plate via a short length (say about 20mm or so) of tinned copper wire. This is soldered to the top-most "pad" on the left side of the board.

This wire is bent out at 90° to pass through the hole in the second (mounting plate) PCB thence through a tiny hole drilled to match in the Clipsal Plate.

The easiest way to do this is to place the mounting plate in the Clipsal plate and drill a 0.9mm hole right through; ie,

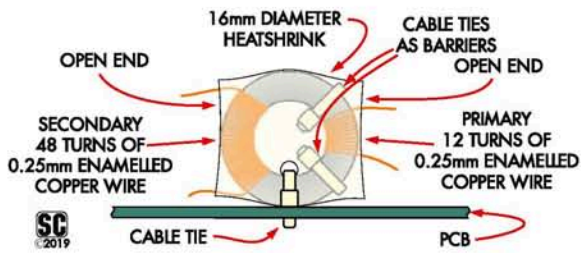


Fig.5: this diagram shows how transformer T1 is wound using 0.25mm diameter enamelled copper wire on a toroidal ferrite core. Once both windings have been made, fit two cable ties as barriers between them and cut the ends off, then slide heatshrink tubing over the transformer and shrink it down. Poke a hole through the tubing with a screwdriver and attach it to the PCB as shown before soldering the wires to the board.

RED and BLACK . . . or BROWN and BLUE?

In our wiring diagrams, we have shown mains Active as RED and mains Neutral as BLACK. But didn't wiring colours change to Brown (Active) and Blue (Neutral) quite some time ago?

Yes they did . . . and theoretically, we should be showing the "approved" SAA wiring colours of Brown and Blue.

However, even today you will find that the vast majority of electrical installations (ie fixed wiring) are done in the "old" colours of Red and Black.

Because you are *much* more likely to find red and black wiring in your home, we have stuck with that you will likely encounter.

use the mounting plate as a template.

When later assembled, the wire is bent back to be flush with the surface of the Clipsal plate so that when the aluminium touch plate is clipped into place, it makes intimate contact with the wire.

(This wire is not soldered or otherwise fastened to the touch plate).

Programming IC1

If you purchased a pre-programmed PIC microcontroller from the SILICON CHIP ONLINE SHOP, you can plug it into the socket now, after bending its leads to suit. Make sure its pin 1 dot is orientated as shown in Fig.3.

If you have a blank PIC12F617 IC, you will need to download the firmware (HEX file) from our website, then load it into the chip using either a universal programmer or a PICkit 3 or PICkit 4 in-circuit serial programmer (or similar) with a breakout board.

Our PIC/AVR Programming Adaptor board from the May and June 2012 issues (siliconchip.com.au/Series/24) is suitable.

If using a universal programmer, use the supplied software. For the PICkit 3 and PICkit 4, you can use the MPLAB IPE (integrated programming environment), part of the MPLAB IDE (integrated development environment), which is a free download from the Microchip website and is available for Windows, macOS and Linux.

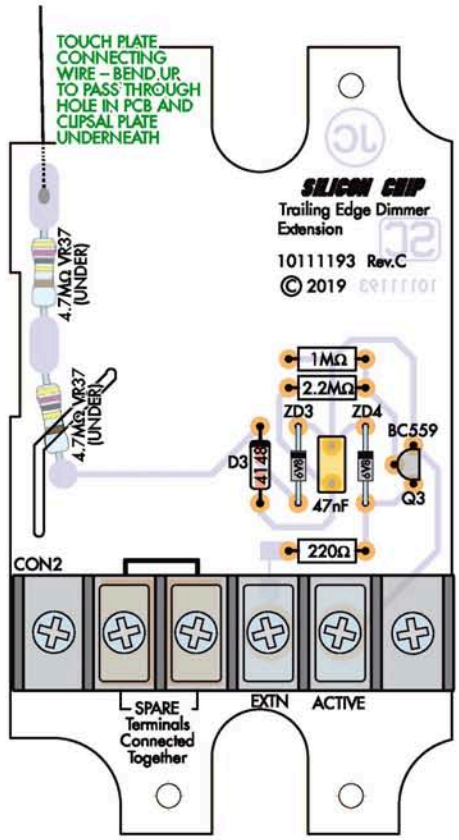


Fig.6, the Dimmer Extension PCB overlay, for when you want two or more dimmers controlling the same light or set of lights. There are just a few components on it, so it should be easy and quick to build as long as you are careful to fit them in the locations and with the orientations shown. Again, a short length of tinned copper wire bends down 90° to pass through the second (mounting) board, thence through the Clipsal mounting plate, to make contact with the touch plate.

Mounting the board

The backing plate PCB is sized to fit precisely into the Clipsal C2031VX blank plate.

This then allows you to mount the main Dimmer PCB. Fit the backing plate into the Clipsal plate, noting that the screen printed side should be visible once you have finished; the PCB will only fit with one orientation.

Mark out the centre for the hole required for the lens to fit into the Clipsal plate and note that this hole isn't drilled when building the extension board, or if you have opted to leave out the infrared remote control feature. We have provided cross hair screen printing to show the centre position required on the backing plate. Drill the hole 9mm in diameter.

The same sized hole needs to be drilled in the Aluminium plate. Drilling this out carefully against a block of timber; starting with a smaller diameter drill and reaming the hole out to 9mm will produce a better hole finish compared to using a 9mm drill bit.

Also drill the 0.9mm hole for the touch plate connection wire now. This hole only is made in the Clipsal plastic plate, not the Aluminium plate.

These three photos show the location and mounting of the touch plate connection wire. It passes through the mounting PCB and Clipsal plate to contact the cover when it is pushed on.

Remove the backing PCB and insert four M3 x 10mm screws in from the underside of the PCB at each corner mounting position and attach two M3 nuts to the top side. Tighten the first nut but leave the second nut only just touching the first nut. Solder the two nuts together and solder the lower nuts to the PCB. Once the solder joints are cool to the touch, remove the screws.

Solder a 15-20mm length of tinned copper wire to the underside of the main dimmer PCB, at the end of the 4.7MΩ safety resistor. This is directly opposite the hole for the touchplate connection on the backing plate PCB. As with the safety resistors, this wire is surface-mounted to the bottom of the PCB.

Final assembly

Fit the backing plate PCB into the Clipsal plate and press it in so the PCB sits tightly inside.

You can secure it with some silicone or polyurethane sealant, to ensure the PCB stays in place. To do this, apply a few dabs of the sealant to the underside of the PCB before inserting into the Clipsal blank plate.

Insert the Fresnel lens, then align the dimmer PCB over the backing plate PCB and feed the touchplate wire through the backing plate hole and through the Clipsal blank plate hole. Then secure the dimmer PCB to the backing plate PCB using the M3 x 10mm screws.

As you do this, ensure that the touchplate connecting wire is now protruding through the backing plate

Fig.7: this warning panel should be photocopied or printed and glued to the face of the Clipsal switch plate before the aluminium touchplate goes on top (make sure it doesn't cover the wire which touches the aluminium touchplate). It's a reminder to anyone taking the dimmer off the wall that there is live wiring and circuitry behind it.

Testing before installation

Since you're probably going to have to pay an electrician to come around to your house and install the dimmer(s), you will want to be sure they are working first. The easiest safe way to do this is to use a surface GPO mounting block to suit the switchplate(s), screwed to piece of insulating material (eg, MDF) large enough to cover block.

You will also need a mains extension cable cut in half to provide power to the circuit (from a power outlet) and a lamp (of the type you are using) to plug into the socket.

Strip the outer and inner insulation of the ends of the cut mains cord and drill holes in the sides of the surface mounting block, just large enough for the mains cable to fit through. Go through the installation procedure in the main text of this article, ensuring that you conduct the safety checks as described. Use a double-screw BP connector to join the mains Earth wires in the two halves of the cable.

The socket end of the mains cord will connect to your lamp load. Most dimmable LED lamps have a mains plug attached so you can simply plug it in. If using another type of lamp, you will need a suitable luminaire and a safe arrangement to connect it to a mains plug.

In summary, if your final installation will include the mains Neutral wire, you can connect the Active wire from your mains plug lead to the "A" terminal on the Dimmer, the plug and socket lead Neutral wires to the "N" terminal (the terminal barrier used will easily accommodate two wires per terminal) and the socket Active wire to the "LAMP" terminal.

If you will not have the mains Neutral available in your final installation, instead you will need to join the plug and socket lead Neutral wires together (again use a BP connector), the plug Active wire to the "A" terminal and the socket Active wire to the "N" and "LAMP" terminals as shown below. Make sure it is not plugged in while you connect it!

Attach your surface mounting block to the MDF (etc) so that none of the mains wiring is exposed. You can then plug the lamp into the socket and the mains plug into a wall outlet and wait at least nine seconds (to skip the Calibration step, as explained in the text). You can then test that the touch and (if fitted) infrared remote control.

If the lamp you're using to test is the same one that will be used in your final installation, you can also complete the calibration procedure – see the steps below. It's easier if you do it now, since it's much easier to switch the dimmer on and off at this stage.

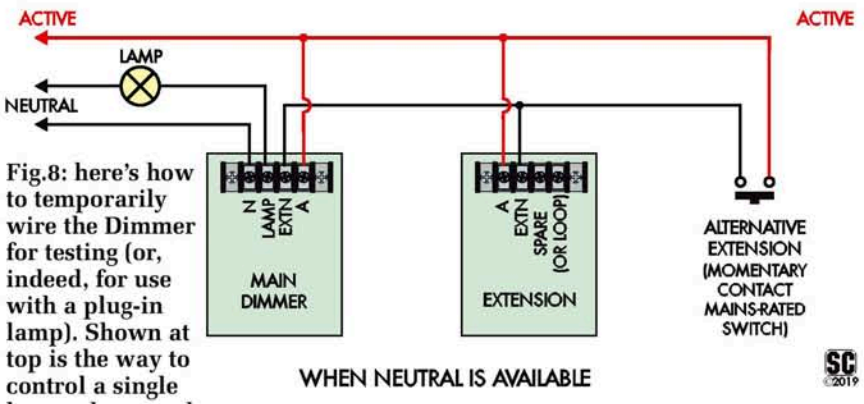
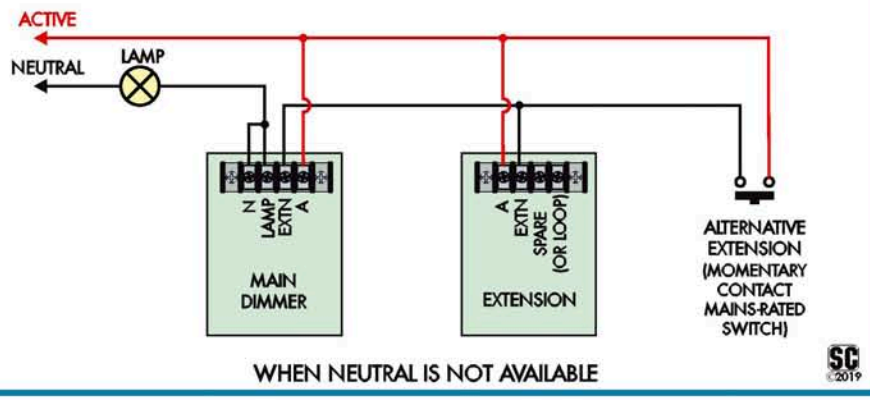


Fig.8: here's how to temporarily wire the Dimmer for testing (or, indeed, for use with a plug-in lamp). Shown at top is the way to control a single lamp when you have both Active and Neutral available, while the lower diagram shows the connections when no Neutral is available. If you are not going to use an extension dimmer or push button, simply ignore those connections.



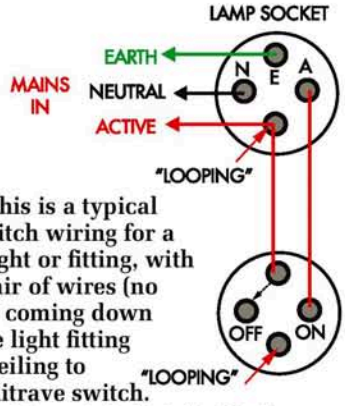


Fig.9a: this is a typical light switch wiring for a single light or fitting, with just a pair of wires (no neutral) coming down from the light fitting on the ceiling to the architrave switch. One point to note is that the Earth wire is often not used in many older homes but in any case, the Earth plays no part in the dimmer design. The "looping" terminal is merely a handy not-connected termination point.

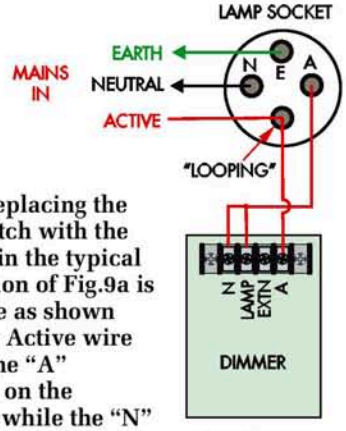


Fig.9b: replacing the light switch with the dimmer in the typical installation of Fig.9a is as simple as shown here: the Active wire goes to the "A" terminal on the dimmer, while the "N" and "LAMP" terminals on the dimmer are joined and go back up to the Active terminal on the light fitting. Ensure you turn off the power at the switch board before installing the dimmer!

PCB and the Clipsal blank plastic plate. Bend this wire over by 90° to sit against the face of the plate. This will contact the Aluminium plate when fitted, providing the touch sensing connection.

Fig.7 is a safety warning label which you should print out and glue to the plastic plate. This is so that if the Aluminium plate is removed, the warning to switch off mains power at the switchboard will be seen.

You can also download this label from the SILICON CHIP website for free as a PDF file, listed in the ONLINE SHOP under "Panels & Case Pieces".

Building the extension board

You only need this board if you want more than one touch plate to control the same set of lights.

The extension circuit is built on a PCB coded 10111193 which measures 58.5 x 104mm. You will also need a Backing Plate PCB (coded 10111192) to attach the extension board to the Clipsal blank plate, which once again is used with a blank aluminium faceplate.

As with the main Dimmer board itself, if mounting the extension board to a metal wall box (as used in a brick wall), it must be spaced from the metal box using a 30mm or deeper mounting block. Alternatively, it can be mounted directly to a stud (Gyprock) wall using standard mounting hardware or mounted on a thin or standard height surface-mounting box.

Fig.6 is the PCB overlay diagram for the extension board. The resistors, zener diodes, the diode and transistor can be fitted where shown, in that order. The resistor colour code table shows the colours – note that some resistors will not normally be available in 1% types.

It's a good idea also to use a digital multimeter to measure each value. Note that the two 4.7MΩ resistors on the underside of the PCB are mounted later.

The good news is that the two zener diodes, ZD3 and ZD4 are the same value, so you only need to watch the polarity of these two components, plus diode D3. The orientation of transistor Q3 also matters but it will be correct if you fit it with the flat face as shown. You will probably need to bend the leads slightly (eg, using small pliers) to fit the PCB pads.

Solder the single capacitor in place next, then mount the screw terminals. As with the main board, attach the screw terminals using two 20mm M3 machine screws and nuts first before soldering the pins and use plenty of solder, to ensure good joints.

The two Vishay 4.7MΩ VR37 resistors are surface-mounted on the bottom on the board in the same manner as for the main board. Once again, do not substitute these parts. They are high-voltage resistors that are rated at 2.5kV RMS and are specified for safety. They are light blue. Bend the resistor leads near the end of the resistor, then trim them so that they sit flat on the pads before soldering them.

The procedure for attaching the extension PCB to the Clipsal plate using the backing plate PCB is the same as described for the main dimmer PCB. The exception is that you don't drill the hole for the lens.

Installation

By now, you have tested the dimmer according to the procedure shown in the panel and diagrams of Fig.8.

Use these, in conjunction with the diagrams of Fig.9 to show how installation is done in the two typical scenarios – no Neutral available (the more usual – Figs.9a and 9b) and the other possibility, Neutral available (Figs. 9c and 9d).

No extension dimmer nor switches are shown in the Fig.9 diagrams; you'll need to refer back to Fig.8 for their wiring.

The dimmer and extension plates must be securely attached to a wall before mains power is connected. Of course, the power must be switched off at the fusebox or breaker panel while installing the unit.

Before installing these units, carry out the following safety check. Switch your multimeter to its highest resistance measurement range and check the resistance between the Active terminal and the touchplate contact.

Do this for both the main dimmer board and the extension board, if using an extension. The resistance should be close to 9.4MΩ. This verifies that the touchplate will not be hazardous.

If you aleady have an older-style

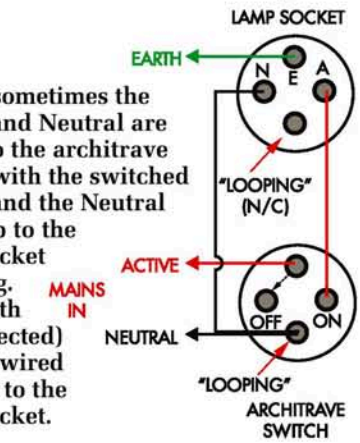


Fig.9c: sometimes the Active and Neutral are wired to the architrave switch with the switched Active and the Neutral going up to the lamp socket or fitting. The Earth (if connected) is often wired directly to the lamp socket.

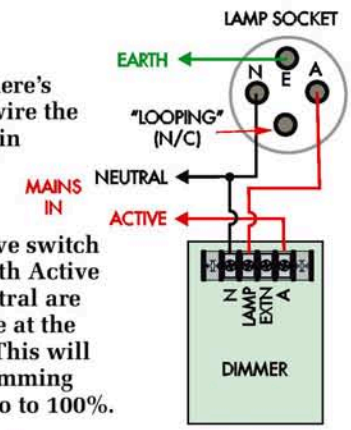


Fig.9d: here's how to wire the dimmer in place of the existing architrave switch when both Active and Neutral are available at the switch. This will allow dimming from zero to 100%.

dimmer that you're replacing, (perhaps you want to change from incandescents to LEDs?) the new dimmer circuit is easily installed into because the wiring is the same, connecting to the incoming Active (brown or red) and lamp via the Neutral (blue or black) wires.

This is shown at the bottom of Fig.8. This example includes one extension board plus a separate on/off momentary (mains-rated) pushbutton switch but these extra units are optional and can be omitted if not needed.

If you are installing a new dimmer and you can run the incoming mains Neutral wire to the dimmer mounting location, that's even better, as it will give you a full range of dimming from off all the way up to 100% (full brightness).

As shown in Fig.8, the extension module requires an incoming Active connection and an extension wire which connects to the EXTN input on the dimmer. It can be installed into existing 2-way switch wiring, or you can have an electrician install new wiring if this is not already present.

The unconnected loop terminals on the extension board can be used to terminate any extra wires that need to be joined.

The momentary switch option, as shown in Fig.8, can be used in an architrave switch surround, making it easier for installation where space is limited such as in a door surround.

Calibration

If you were able to connect the incoming mains Neutral to the Dimmer module, then there is no need to perform any calibration. It is initially set to provide the full incoming mains voltage to the lamp when switched on fully.

If there is no separate Neutral wire available, the dimmer will get its supply power through the lamp. The dimmer will need to be adjusted to give the maximum lamp brightness without flickering.

The adjustment needs to be started within nine seconds of power being applied to the dimmer. Otherwise, the dimmer will go into its normal operating mode.

Powering up the dimmer involves switching on the light circuit at the electrical switchboard. As soon as you can and before nine seconds has elapsed, press and hold the touch plate continuously and wait until the light starts to increase in brightness. Remove your hand as soon as the lights start flickering, which should occur close to full brightness.

Then, press and hold the touch plate until the lights dim to a point below where there is no flickering. Remove your hand again and then do a quick press on the touch plate to switch off the light(s). This action will set the maximum lamp brightness at the last used brightness level. The dimmer will use this level from now on as the maximum brightness setting, even if mains power is lost.

Recalibration of the maximum brightness can be performed by repeating the procedure, starting by switching off power to the lights circuit. The maximum brightness can then be set at a higher or lower level than the previous setting.

Note that the rate at which the lamp brightness increases during this procedure is purposefully slow, so you can set brightness with reasonable precision. Note also that once you start the calibration procedure by touching the dimming plate, you have up to five seconds after you remove your hand to re-apply it to the plate to start reducing the brightness.

There is another five second timeout period after you removing your hand having reduced the brightness before you touch it again, to switch off the lamp.

If you do not touch the plate before these five second periods elapse, calibration will be aborted and the previous maximum brightness value will be used. You will have to start again.

Keep in mind that the calibration should be done with the lamps you are going to use with the dimmer. If you use different LED lamps or an incandescent lamp, the maximum non-flickering brightness setting may be different.

In operation

Note that the dimmer plate usually runs just warm to the touch, due to the dissipation within Mosfets Q1 and Q2 of around 1W total.

The remote control must be directed toward the receiver on the main dimmer plate to obtain reliable operation. We found that our prototype worked well up to 7m away from the wall plate, as long as the remote control was correctly aimed. SC

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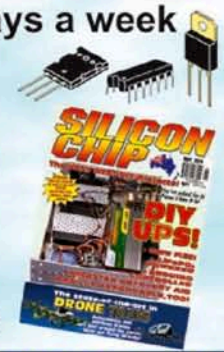

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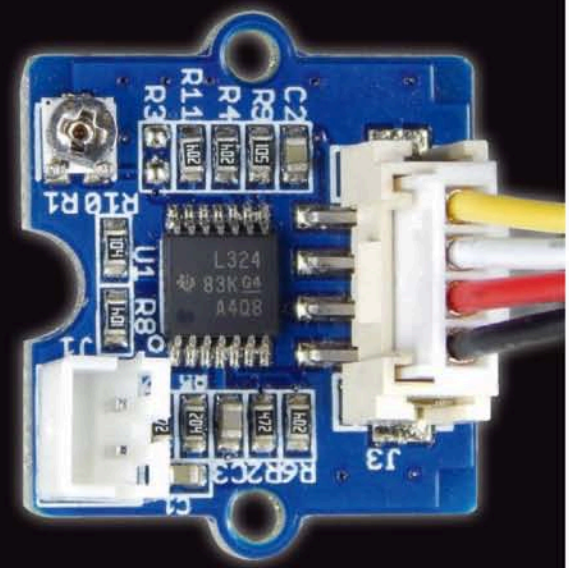
Galvanic Skin Response



This Seeed/Grove-designed Galvanic skin response sensor measures the changes in resistance of human skin, which indicate changes in mood, apprehension or other psychological phenomena. It's smaller than a stamp and comes with a pair of sensing electrodes. It also has an analog voltage output, making it easy to use with any micro or a digital multimeter.

These days, the term "Galvanic Skin Response" is regarded as obsolete; it is instead known as Electrodermal Activity or EDA. Nonetheless, GSR is still pretty widely used.

GSR is often regarded as the primary body parameter measured in 'lie detectors', or "polygraphs" as they're known in the USA. However, GSR is only one of the many physiological indicators monitored in polygraphs; others are blood pressure, pulse rate and respiration.

We should point out that despite the widespread use of polygraphs throughout the USA and other countries, there is a great deal of doubt in scientific circles about their accuracy and reliability. They supposedly can indicate when a person gives false answers to questions.

Polygraph evidence is currently inadmissible in New South Wales courts, under the Lie Detectors Act of 1983. However, the High Court of Australia is yet to consider the admissibility of polygraphic evidence at a federal level.

The first suggestion that human sweat glands were involved in creating changes in the electrical conductivity of the skin was made in Switzerland in 1878, by researchers Hermann and Luchsinger. Then in 1888, the French neurologist Fere demonstrated that skin conductivity could be changed by emotional stimulation and also that this could be inhibited by drugs.

Pioneering psychoanalyst Carl Jung, in his book "Studies in Word Analysis" (1906), described experiments using a GSR meter to evaluate the emotional sensitivities of patients to lists of words during word association sessions.

Although the first polygraph was invented in 1921 by John Augustus Larson at the University of California, it only monitored only blood pressure and respiration. Larson's protege Leonarde Keeler updated the device in 1939 by making it portable and adding the monitoring of GSR. His device was purchased by the FBI and became the prototype of the modern polygraph.

So what is GSR/EDA?

The electrical conductivity of our skin is not under conscious control, but modulated by our sympathetic autonomous (subconscious) nervous system. Therefore, it responds to our cognitive and emotional states.

Initially, it was thought that modulation of sweat gland activity by the sympathetic nervous system was solely responsible for the changes in GSR/EDA, and this is still regarded as the main factor. However, it's now believed that there are also accompanying changes in blood flow and muscular activity which affect conductivity.

GSR/EDA sensors are usually fitted to the fingers because our hands and feet have the highest density of sweat glands on our bodies (200-600 sweat glands per cm^2). In fact, the palms of our hands and the inside of our fingers are ideal locations for sensing GSR/EDA, and you don't have to take off your shoes and socks!

The Seeed/Grove GSR module

The Seeed/Grove-designed GSR sensing module is tiny, measuring only 24 x 20 x 9mm, including the two JST 2.0 PH-series SIL headers.

The unusual shape of the PCB, with semicircular cut-outs at two ends which host the 2mm mounting holes, is because the module was designed as part of Seeed Studio's "Grove" module system, a standardised prototyping system.

There are many modules available in the Grove system, including sensors for light, IR, temperature, gas, dust,

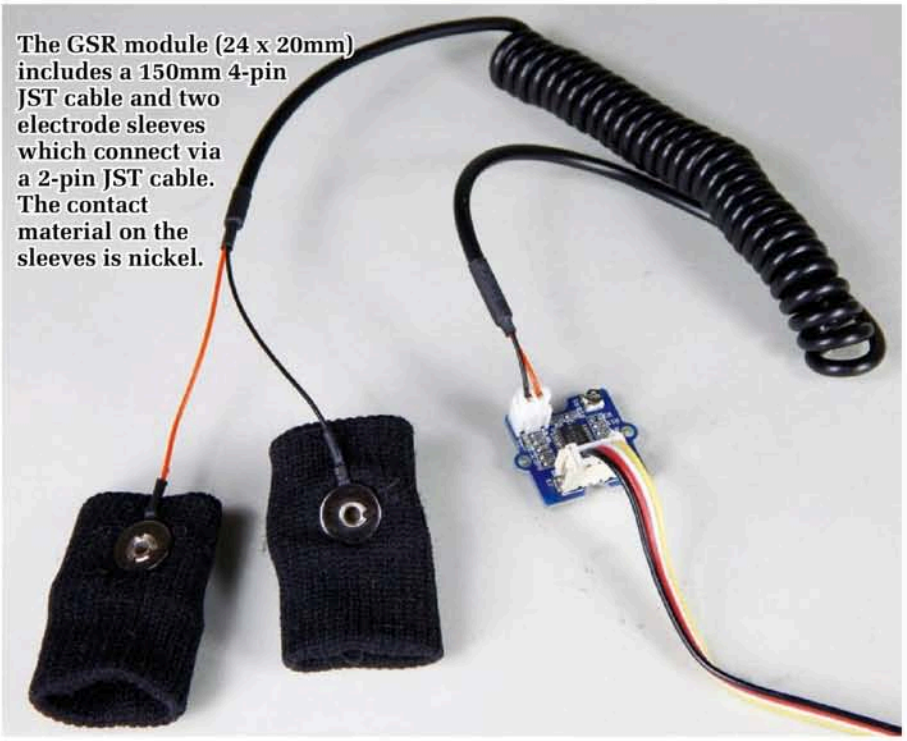
acceleration and the Earth's magnetic field to name just a few.

All of these modules have a standardised connector system, and Seeed has also produced shields and similar "piggyback" boards to make it easy to connect multiple Grove modules to micros like the Arduino, the Raspberry Pi and the Beaglebone series.

Since the modules come with a cable fitted with a 4-pin JST 2.0 connector at each end, it's quite easy to connect a single module like this to a board such as a Micromite, or even to a digital multimeter (DMM).

This module isn't quite as affordable as some of the other modules we've looked at in these articles, perhaps because it comes with a pair of "finger sock" electrode sleeves together with suitable cables to connect to the module. It also comes with the aforementioned 150mm-long cable for connection to the micro.

The cost for the module plus these extra parts ranges between $15.50 (on AliExpress) and $20.80 (from GearBest). There's also a very similar module made by SichiRay, available from AliExpress for $15.70.



The GSR module (24 x 20mm) includes a 150mm 4-pin JST cable and two electrode sleeves which connect via a 2-pin JST cable. The contact material on the sleeves is nickel.

Inside the module

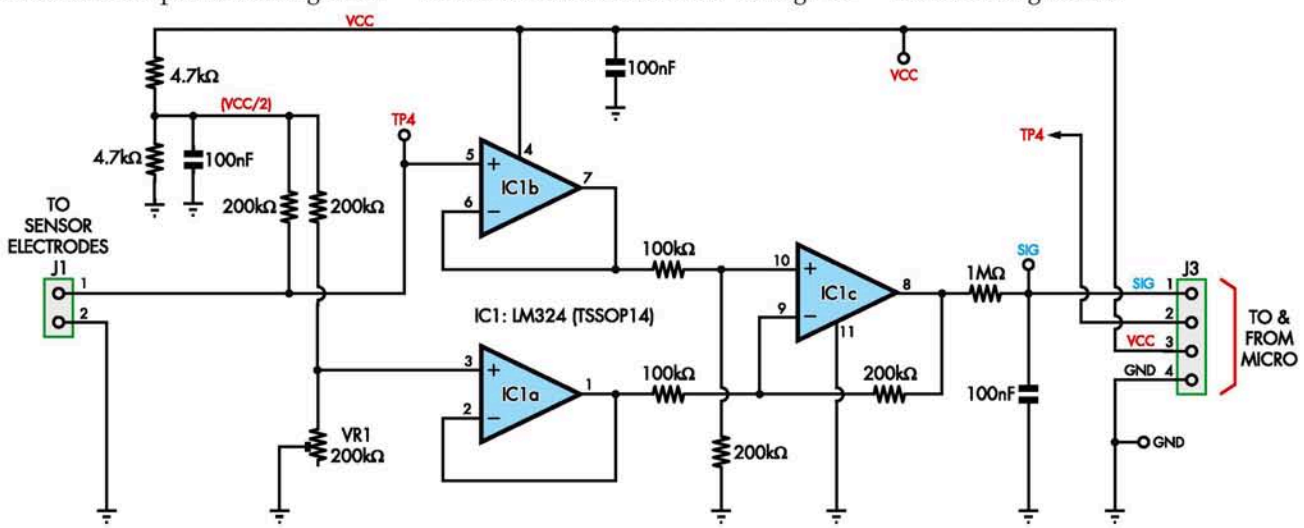
There's not a great deal to the Seeed/Grove GSR sensor module, as you can see from Fig.1. It uses an SMD version of the LM324 quad op amp (IC1), with three of its amplifiers connected in the standard instrumentation amplifier configuration. IC1c is used as a standard differential amplifier with a gain of 2.0, while IC1b and IC1a are unity-gain buffers driving its two inputs.

But instead of having a gain setting resistor connected between the inverting inputs (-) of IC1b and IC1a, as is typically the case with a purpose-designed instrumentation amplifier, the input buffers are left with unity gain.

To the left of IC1b and IC1a is the simple circuitry used to sense the skin conductivity between the two sensing electrodes, which are connected to J1. At the top is a resistive voltage divider which derives a reference voltage of $V_{CC} \div 2$, or 2.5V when the module is powered from a 5V supply.

This reference voltage is used to bias non-inverting (+) inputs of both IC1b and IC1a via 200kΩ series resistors.

Since pin 1 of J1 is connected to the + input of IC1b (pin 5), the voltage at this pin will vary according to the skin conductivity between the two electrodes. On the other hand, the + input of IC1a (pin 3) is simply connected via small trimpot VR1 to ground, and the pin 2 input of J1 also connects to ground.



SEEED/GROVE GSR SENSOR MODULE

Fig.1: complete circuit diagram for the Seeed/Grove GSR sensor module. Non-inverting input pin 5 of IC1 varies from 0-2.5V (5V DC supply) depending on the conductivity of your skin. VR1 adjusts the voltage at pin 3 of IC1a. The difference between these appears at the pin 8 output of IC1c and goes through a low-pass filter, and then onto pin 1 of J3.

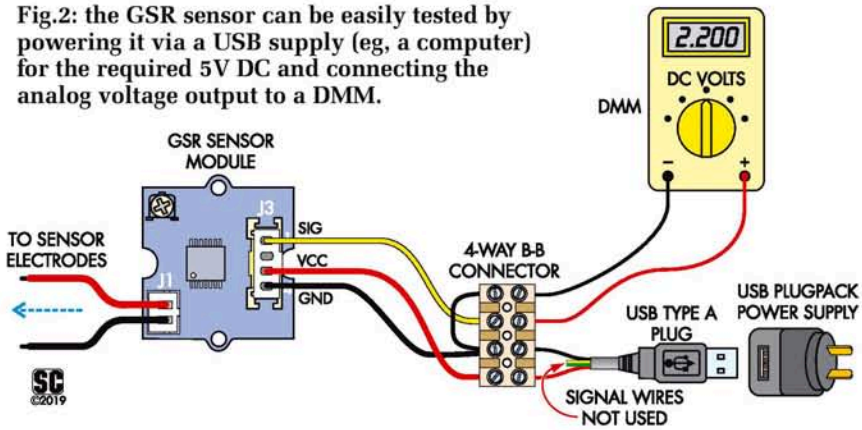


Fig.2: the GSR sensor can be easily tested by powering it via a USB supply (eg, a computer) for the required 5V DC and connecting the analog voltage output to a DMM.

So the voltage applied to pin 5 of IC1b will vary between near-zero and almost +2.5V, depending on the skin conductivity of the connected person. The voltage at pin 3 of IC1a can be varied over the same range using VR1. This allows VR1 to set the full-scale output voltage of the module when the electrodes are open-circuit.

Note that when the electrodes are worn, the maximum current that could flow between them is 12.5µA (2.5V ÷ 200kΩ). This is too low to be consciously sensed and certainly not enough to give an electric shock.

So the variations in skin conductivity between the two sensing electrodes connected to J1 cause changes in the voltage difference between pins 5 and 3 of IC1.

The output voltage from pin 8 of IC1c is this difference. A simple 2Hz low-pass filter comprising a 1MΩ series resistor and a 100nF capacitor is connected between pin 8 of IC1c and pin 1 of J3, the power supply/output connector.

Pin 2 of J3 is connected to TP4 and pin 5 of IC1b, which allows you to monitor the voltage across the GSR electrodes with a DMM if necessary.

Trying it out

Probably the simplest way of trying out this module is to provide it with a source of 5V DC and use a DMM to monitor its analog output voltage, as shown in Fig.2. The 5V power supply for the module can come from virtually any USB supply, since it only draws about 1.2mA.

Fig.3 shows how the Seeed/Grove GSR module can be connected to an Arduino Uno or an equivalent microcontroller board, while Fig.4 shows how it's connected to a Micromite LCD BackPack (see our article in the February 2016 issue at siliconchip.com.au/Article/9812).

In both cases, the V_{CC} and GND pins of the module's output connector (J3) are connected to +5V and GND respectively, while the SIG output pin is connected to the A0 pin of the Arduino, or to pin 24 of the Micromite.

I found a very simple sketch for the Arduino in one of Seeedstudio's wikis (siliconchip.com.au/link/aan5). It merely makes a series of 10 measurements of the module's output voltage, adds them together and then divides by 10 to get their average.

This is then sent back to your PC, to be either printed out in Serial Monitor or plotted using Serial Plotter. Then it loops back and repeats this sequence over and over again.

You can see a sample output plot from this sketch in Fig.6. It's called "GSR_Testing_sketch.ino" and we've made it available as a free download from the SILICON CHIP website.

Note that when you first power up the Arduino with the module connected, it's a good idea to set trimpot VR1 to give a readout of around 512 before the electrodes are fitted to anyone's fingers. This only needs to be done once, not every time you apply the power.

For those who want to use the GSR module with a Micromite, I have written a small program in MMBasic. This is identical to the Arduino program, taking a series of 10 measurements and calculating their average. The measurements are then sent back to the PC for display in the MM-Chat window.

It's also shown on the Micromite's LCD screen as a single figure, which changes with each new set of measurements.

Fig.5 shows a screen grab of this program in operation. It's called "GSR module checkout.bas" and is also available for download from the SILICON CHIP website.

This should provide you with a starting place for writing a more elaborate program of your own, perhaps one that displays the growing GSR plot on your PC's screen, like a polygraph display. Once again, it's a good idea to adjust VR1 for a reading of around 512 before the electrodes are fitted.

Fig.5: the sample program running on a Micromite. Connect two fingers to the sensors to display the current skin resistance. Anything ±5% from those initial values indicate a change in mood. A higher reading typically indicates a more relaxed mood, while a lower reading is a tenser mood (greater perspiration, thus decreasing skin resistance).

Breadboarding it

Given how simple the circuit shown in Fig.1 is, you may be wondering whether it's possible to breadboard it. We reckon it wouldn't be too hard.

The only thing you need to be careful of is to avoid any possible leakage currents on the tracks and components connected to the non-inverting inputs of IC1a and IC1b (pins 3 and 5), as this could disturb the readings, especially if the leakage currents were to vary with temperature, humidity etc.

This generally means keeping the breadboard and components plugged into it clean and dry and avoid touching it during operation.

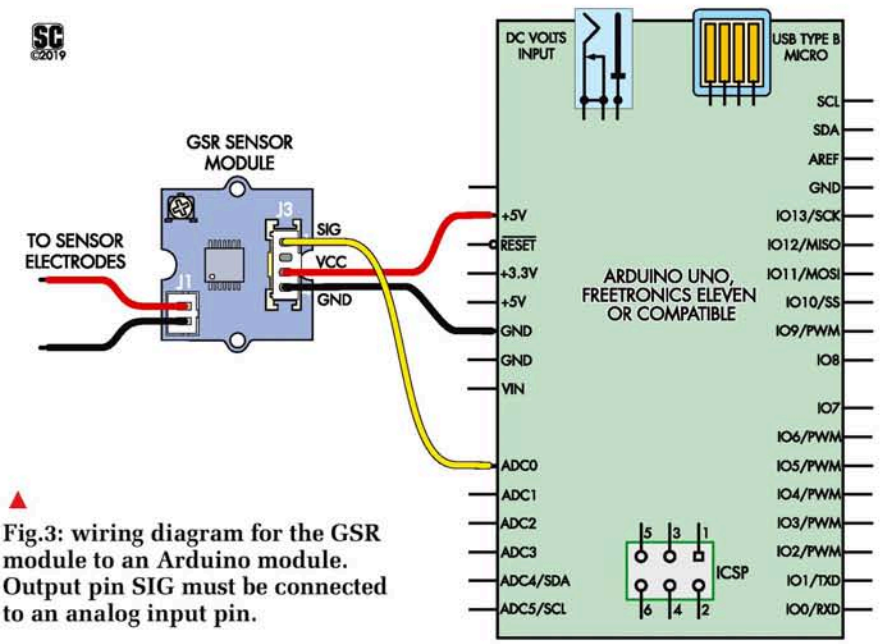


Fig.3: wiring diagram for the GSR module to an Arduino module. Output pin SIG must be connected to an analog input pin.

You could probably even build a little GSR module yourself on a bit of veroboard, using a DIP LM324 IC and a handful of passives, in a similar arrangement to that shown in Fig.1.

Useful links

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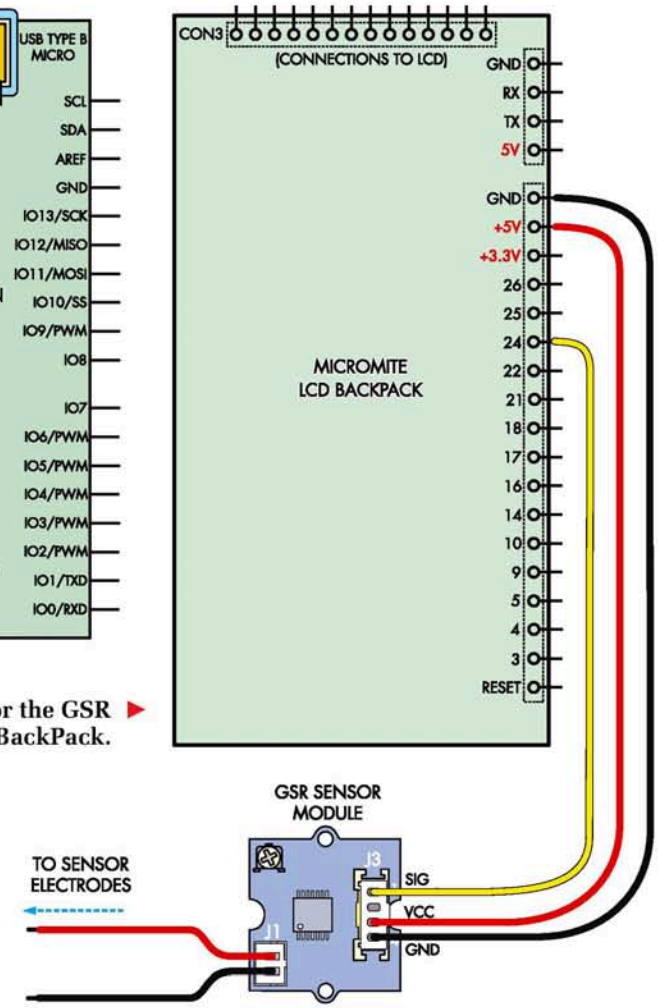
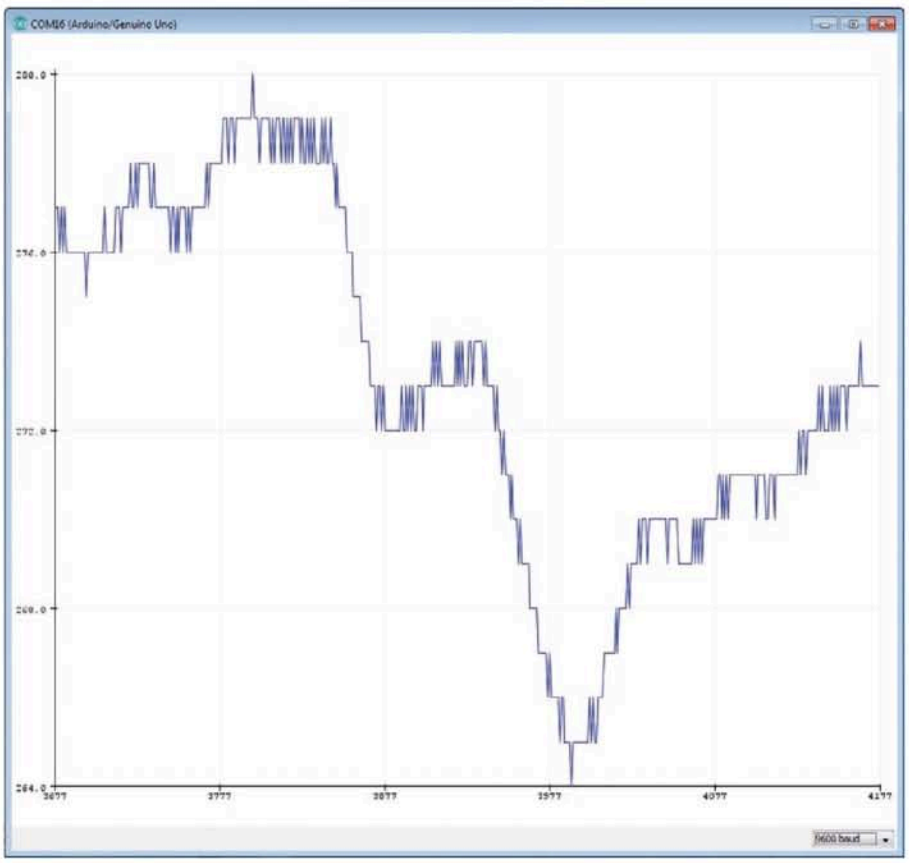
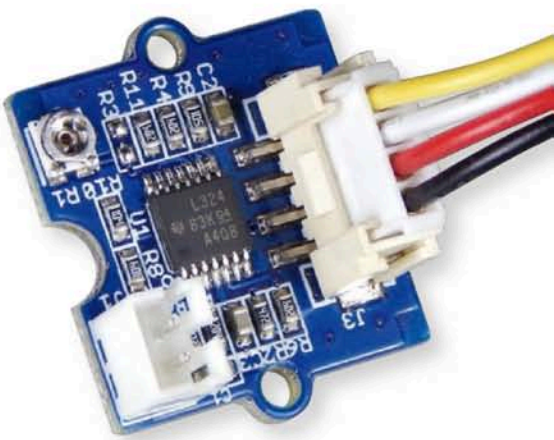


Fig.4: wiring diagram for the GSR module to a Micromite BackPack.



Output plot of the values from the GSR module using the Arduino Serial plotter. The values swing from a high of 280 to a low of 264, even though the reference value is 512, due to the way the module is designed.

The Seeed/Grove galvanic skin response module, shown below at twice actual size, is based on a LM324 op amp and costs around $15.00.



VINTAGE RADIO

By Fred Lever

Astor HNQ Mickey 4-½ valve radio

This is a plain-looking set, and as a four-valve reflex superhet, it isn't particularly good at pulling in weak stations. But it does have one interesting feature in that it uses permeability tuning, which was common in car radios but not so much in mantel sets.

I recently purchased an Astor "Mickey" bread-loaf shaped valve radio set from a character called "Steptoe". That makes it sound like I bought it out of the back of a van in a pub parking lot, from a man dressed in a trench coat. But I actually bought it on eBay. Perhaps that is the modern equivalent of the pub parking lot...

Anyway, I was attracted to this set due to its use of permeability tuning; something I had heard about but never seen up close before. The set looked honest and most of its parts seemed to be present, except for the rear cover.

The set was described as a non-runner and even with the less-than-stellar eBay photos, I could see that one valve was white inside, denoting a loss of vacuum. But I figured that whatever was wrong with this set, I could fix. I mean, how hard could it be? So I went ahead and bought it.

The set arrived very carefully packed into a big box; well done, Steptoe. The parts were mostly original, not having been butchered in some sort of amateur repair attempt, and overall the set appeared to be in good condition, with minimal dirt and corrosion given its age.

A closer inspection revealed that it had been serviced at some point, probably many years ago; I noted that some resistors had been changed and a couple of critical capacitors such as the audio coupling and AGC bypass had been replaced with 1980s-style units.

The output transformer had also been replaced, as the original red and blue wires were cut off close to the attachment points and new leads soldered on top. I'm guessing that all of this work had been done in the 70s or 80s, based on the components used.

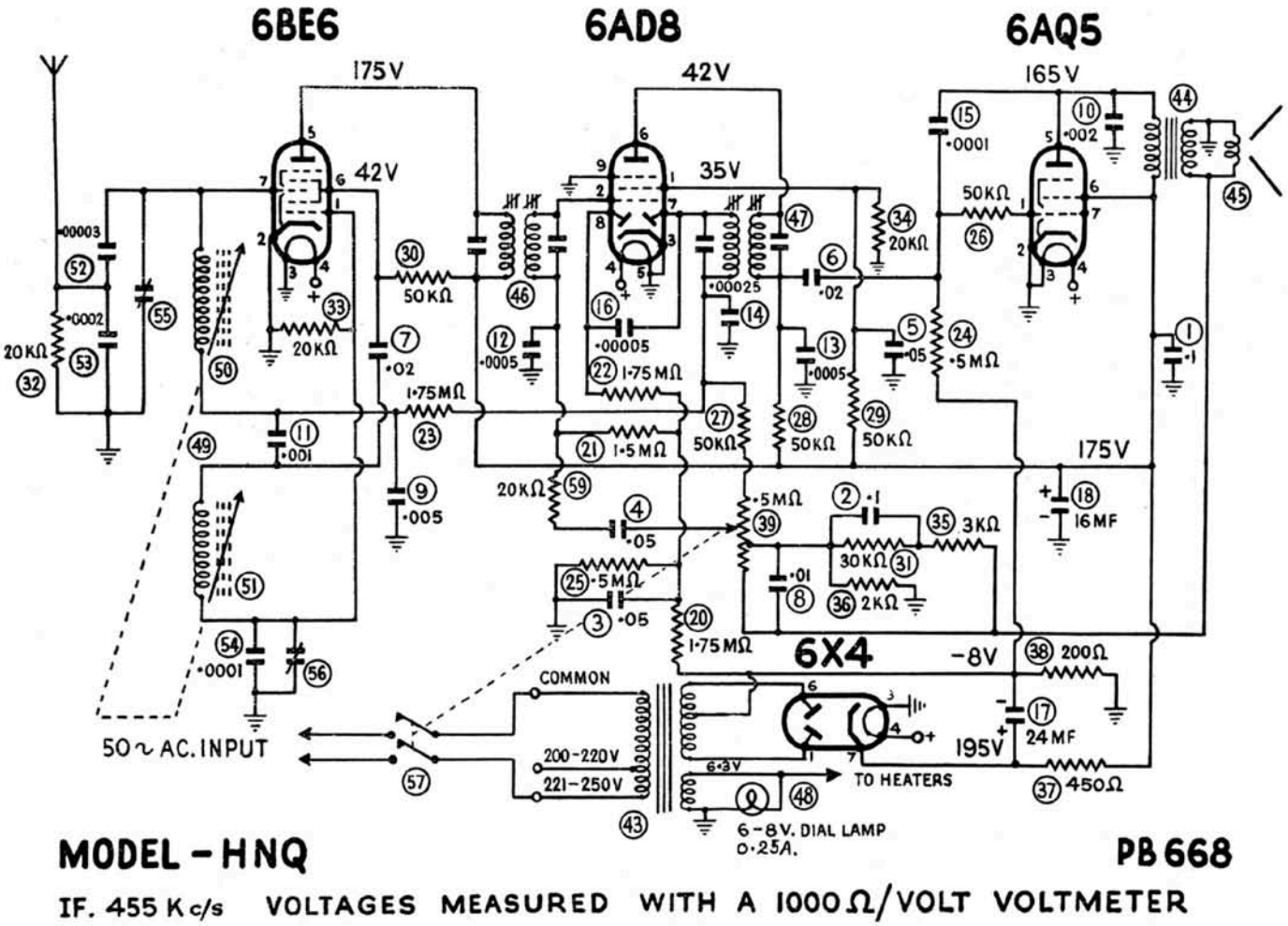
Permeability tuning

You can clearly see the permeability tuning mechanism in the photo of the top side of the chassis removed from the case.

A traditional tuning gang looks like an evenly spaced stack of thin metal plates, often with odd-looking shapes, where every second plate is fixed and the others rotate, thus varying the overlap as one set rotates, changing the capacitance between the sets of plates. But this one looks very different, with pistons that move in and out of coils, geared to the tuning knob so that they move when it is turned.

I guess the main disadvantage of this scheme is that the pistons are quite a bit wider than a capacitive tuning gang but there must have been some reason why the Astor designers decided to use it in this set; most likely, to reduce the cost of manufacturing the set.

Permeability tuning was used in car radios because it was possible to provide push-button presets for the user's



favourite stations. These moved the pistons to a particular position when pressed, corresponding to the previously stored station. But that feature is not present in this set.

Set design

This is a very plain-looking set, with a uniform cream case featuring little other than the speaker grille, which is moulded into the case, the tuning dial and the on/off/volume control knob.

While the circuit design is not quite as "bare bones" as the outside appearance would suggest, it is a standard four-valve reflex superhet design, with no real surprises, other than the unusual permeability tuning.

The reason I've referred to this set as having 4-½ valves in the heading is that, being a reflex set, one of the valves actually does two different jobs. So I figured that was the equivalent of it having at least another half a valve.

In case you aren't familiar with reflex sets, these cleverly re-use an RF amplification stage by coupling audio-frequency signals into the input, superimposed on the RF signals (which are naturally at a higher frequency).

The amplified output is then separated using two filters, one of which removes the low-frequency AF signals and one of which removes the high-frequency RF signals so that the amplified RF and AF can be fed to different points in the circuit.

Unfortunately, this can compromise the performance of that valve which has to do two jobs; after all, it can't be fully optimised for either and therefore is a bit of a compromise.

Still, it would have reduced the set's cost compared to using five separate valves, and the result is certainly better than a four-valve set which does not use reflexing.

The mixer-oscillator is based around a 6BE6 pentagrid converter valve with a 175V HT, while the combined RF/AF amplification stage uses a 6AD8 dual-diode pentode with a surprisingly low 42V HT. The audio power amplifier is a 6AQ5 beam tetrode with 165V HT and the fourth valve is the 6X4 miniature full-wave rectifier.

The converter circuit has a mostly standard configuration, except for controling the antenna tuning and oscillator frequency (as mentioned earlier). It has magnetic coils which slide into the field of ferrite cores, this varies the resonance points and so controls the station tuning (the permeability [inductance] of the air around the cores change).

These are adjusted so that the antenna tuning (as mentioned earlier), oscillator track and stations appear at the right places on the dial, using trimcaps #55 & #56.

The 6AD8 AF/RF amplifier has a plate load comprising the second IF transformer (#47) plus a 50kΩ series resistor (#28). The RF signal for this valve is coupled to grid #1 at pin 2 via the first IF transformer and is fed to the demodulator diode at pin 7 via the second IF transformer.

The demodulated audio is low-pass filtered, to remove the RF signal by 250pF capacitor #14 and fed to volume control pot #39. It is then coupled from the pot's wiper back to the bottom end of the first IF transformer, where it is fed back into pin 2.

The inside back of the Astor HNQ. The damaged 6AQ5 output audio amplifier valve is directly right of the power transformer. The visible two-core power cable was replaced with a proper three-core cable with Earth.

The amplified audio signal then appears at the plate (mixed with the amplified RF signal) but the RF signal is filtered out by capacitor #13 and the resulting audio is coupled to the grid of the 6AQ5 Class-A amplifier via 20nF capacitor #6 and 50kΩ resistor #26.

The 6AQ5 operates as a conventional Class-A amplifier, with a transformer (which also acts as its anode load) to couple the signal to the speaker. This part of the circuit has a very heavy top-cut filter, removing anything above speech frequency. This was necessary as, without it, the stage would become unstable and oscillate.

There is negative feedback from the speaker back to the bottom end of the volume control, with an RC filter network feeding a tap on the volume control pot. This provides bass boost at low volume settings, akin to a loudness control. As a result, the set is a bass lover's delight when the audio is fed into a wide-range speaker. But when driving its own tinny speaker, the boost only serves to overcome its deficiencies.

Fixing it up

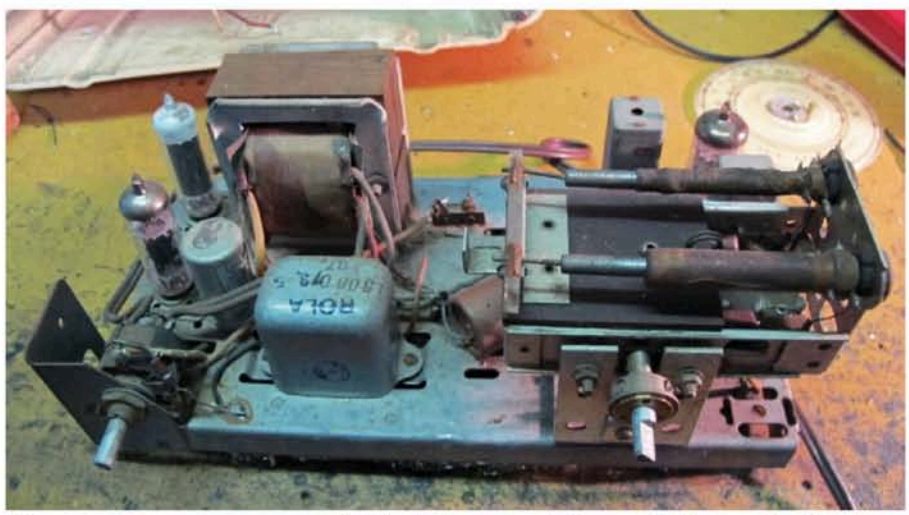
I'm not going to claim that I "restored" this set since I didn't strip it back to individual parts and rejuvenate everything, resulting in an as-new radio. Rather, I simply got it working and gave it a bit of a spiff-up to make it presentable. So I think "fixing" is a more appropriate description. It makes me quite cross when I see sets advertised as "restored" when they still have plenty of rust and dirt evident.

Initially, before I applied any power to the set, I did some safety checks to make sure that the power transformer insulation to Earth was intact and the windings were intact. I also fitted a three-core mains flex in place of the dodgy old two-core cable, retained with a knot.

I used a fabric-covered cable taken from an old toaster, to better suit the era of the set, and I made sure to anchor the cable properly and solder the Earth wire to the set's chassis.

While doing this work, I discovered that the power switch was open circuit. The power switch is integrated with the volume control pot, so I removed it and pulled it apart. I found that the mechanism was working fine but the contacts were severely corroded. A shot of WD-40 and then chemical cleaner fixed that problem and it worked fine after reassembly.

At this point, I had to address the vacuum-less vacuum tube. It had a crack around the base and was undoubtedly beyond my repair abilities. Luckily, I happened to have a 6AQ5 in my spares with the box marked "brand new", so I swapped it into the set.



The contacts on the power switch/volume control (bottom left) were badly corroded; a bit of cleaning brought it back into action.

Testing it out

I poked around the circuit a little more looking for any suspicious shorts but seeing as I didn't find any, I plugged the set into my variac with an in-line power meter and applied 50VAC. The supply circuit breaker did not drop out and the meter hardly moved – so far, so good.

I ramped the variac up to 100VAC and was greeted by a glowing dial lamp, with some power flowing to the set. A voltmeter on the HT rail indicated 30V DC after a couple of minutes. There was no glow visible in some of the valves, so I sprayed WD-40 onto all the valve pins and plugged them back in. They all then lit up; I also noted some hum from the speaker.

I left the set running from 100VAC for about 10 minutes and then checked for any hot parts with an infrared spot (contactless) thermometer. Nothing was getting smelly hot and the HT had crept up to 70V DC. The mains power meter was reading about 20W, which seemed reasonable.

I then applied the full mains voltage and tried to tune into a strong station. I found that the set worked well as long as it was connected to an external aerial. Realistically, to use this set, you need to be in the city or surrounding suburbs so that you have access to nice strong stations and

The underside of the chassis is primarily populated by resistors and capacitors. The photo on the right shows the newly fitted electrolytic capacitor which reduces audible hum.

even then, you would at least need to string a wire around your living room (if you couldn't run a longer outdoor antenna).

Unfortunately, these days in the suburbs of Sydney, there is a lot of interference to the AM broadcast band, from switchmode-based lighting (CFLs and LEDs), poorly installed solar panel inverters, overloaded street transformers and so on. So it wasn't surprising that I needed a decent aerial to get decent reception.

Checking its operation

I then checked all the DC voltages and found most to be as shown on the service manual circuit diagram, with -8V back bias indicating that the set had the expected current draw. The hum level was a bit high though, with HT ripple measuring about 0.5VAC at the HT 16µF capacitor (#18), increasing to about 2VAC when tuned into a strong station, with the audio modulating the rail!

So I fitted a new high-voltage electrolytic capacitor across #18, leaving the original in place. That drastically reduced the hum, both audibly and on the scope.

I probed the audio both at the demodulator diode output (across 250pF capacitor #14) and at the input to the 6AQ5 amplifier valve. The loss of high-frequency information due to the top-cut was readily visible upon comparing the resulting traces.

I also checked the operation of the oscillator and measured a clean ~1.5MHz sinewave at pin 1 of the 6BE6. I could also see that the mixer was working nicely by probing the 6BE6's grid, which revealed a mix of the incoming RF signal and the oscillator signal, as expected.

With the set up and running, I popped it back into the cabinet and had a listen via the massive Rola 5C speaker. I had to shuffle both sets of controls around a bit by loosening the fixing nuts and bolts to get them in the best position to line up with the cabinet holes. The best that I can say about its sound quality is that it is "pleasant".

Aesthetic restoration

Having established that everything was working well, I removed the chassis again and cleaned it up.

I brushed the top of the chassis with Jaycar PCB cleaner to remove the dirt and applied a bit of black paint to the rusty laminations on the power transformer. I then sprayed a light coat of Jaycar PCB clear coat over the lot, taking care not to get any of that into the tuning mechanism.

That improved the appearance of the chassis no end, so I did the same to the speaker and left them to dry while I had a go at the cabinet.

The cabinet was in good shape with just a couple of cracks and finished in a custard colour they call cream. I gave it a good wash in warm water and rubbed it back with soap inside and out. Once that was done it did not look so bad. I had considered painting it blue or red as I have done to other similar sets, but seeing I don't have a cream radio, I left this one as-is.

I removed a lot of marks and ingrained dirt spots with a good rub over with 0000# steel wool, followed by car polish and a wool buff. This just exposed all the imperfections on the surface of the plastic, so I backed the shine off a bit by polishing the plastic with a fine abrasive pad and left it at that.

The last thing to do was cut up and fit a replacement backplate. I could not find a picture of what shape was fitted originally so I just cut up a paper template from my imagination until it fitted into the back.

I then cut a scrap of fibreboard to the shape of the template and drilled the four securing holes. Once it fitted in OK, I cut a big chunk out of the top to form a handle which also acts as a vent for hot air to escape. I then cut a few slots toward the bottom for the cords to pass through, and others to let in some fresh, cool air.

The fibreboard tends to fluff at the edges where it was cut, so I sprayed the whole thing with a couple of thick coats of automotive filler undercoat to hold it together. Then, as I had a nearly empty can of iridescent Hot Red paint, I emptied it onto the back for a bit of contrast with the case. Whether you consider the final result good or not is a matter of taste. SC

CIRCUIT NOTEBOOK

Interesting circuit ideas which we have checked but not built and tested. Contributions will be paid for at standard rates. All submissions should include full name, address & phone number.

AVR-based inductance/capacitance/frequency meter

SILICON CHIP has published several inductance/capacitance meters over the last ten years, and they have mostly been based on Neil Hecht's 1998 design.

This incorporates the unknown component into a wide-range oscillator and measures the resulting frequency shift to determine the component value.

His original design used an LM311 high-speed comparator. This one is slightly different because it uses the more widely available LM393 dual comparator. The SILICON CHIP May 2008 (siliconchip.com.au/Article/1822) design used the internal comparator in a PIC16F628A microcontroller.

The second stage of the dual comparator acts as a Schmitt trigger buffer to "square up" the oscillator's output signal and make it easier for the micro to measure its frequency accurately.

The result is a relatively simple and accurate L/C/*f* (inductance, capacitance and frequency) meter which measures inductance from 100nH to 700mH, capacitance from 0.1pF to 800nF and frequency up to 6MHz.

The unit has an automatic calibration system so that the readings are as accurate as possible.

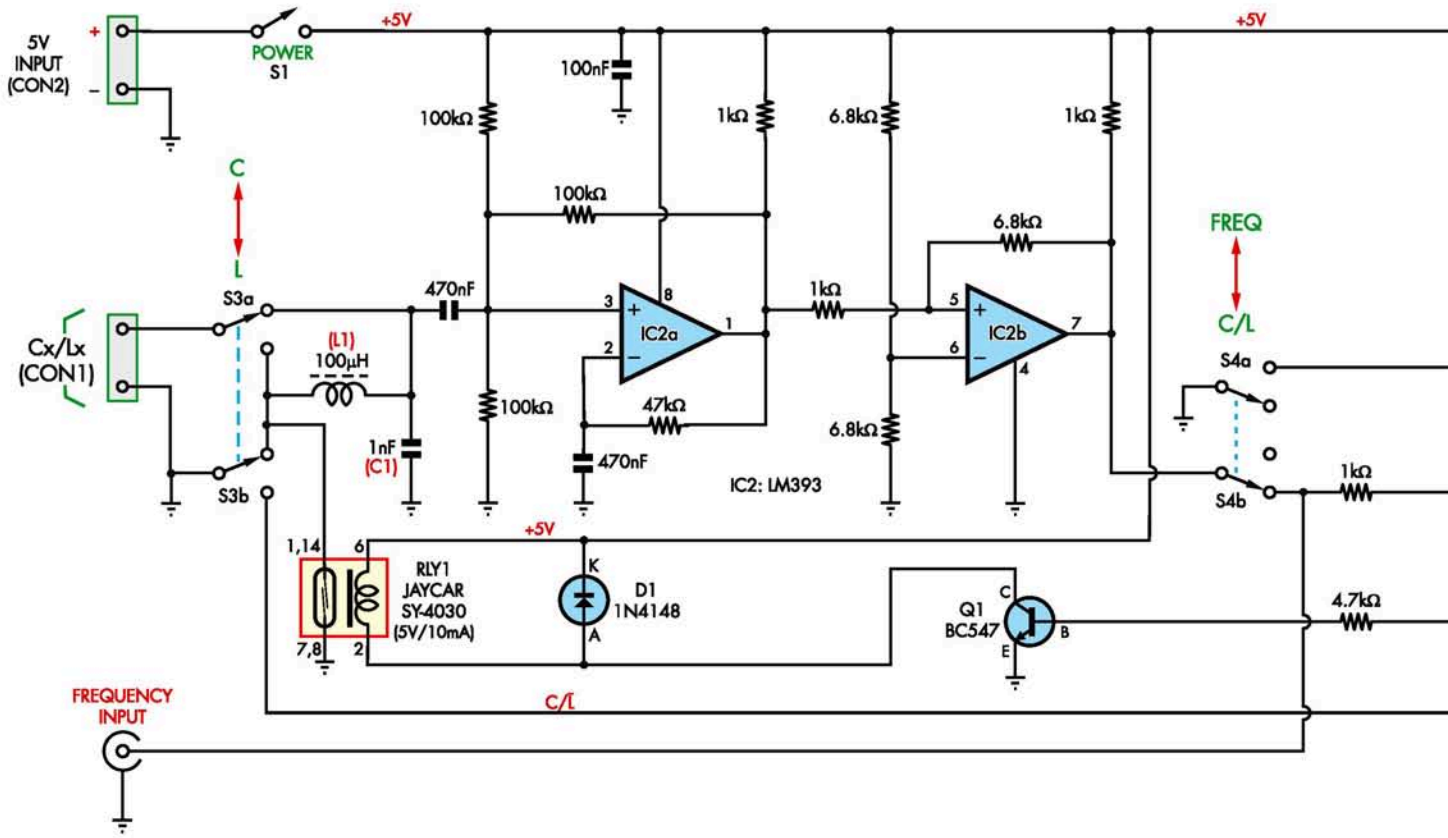
As with other similar designs, if the device under test (DUT) is an inductor, it is connected in series with known-value inductor L1, while if it is a capacitor, it is connected in parallel with known-value capacitor C1. In both cases, this results in a lower oscillation frequency.

The pre and post frequency readings are fed into a mathematical formula, along with the values of the known components, to compute the value of the DUT.

When the circuit is powered up, it performs a three-second automatic calibration procedure, during which time digital output PD3 (pin 5) is high, switching on Q1 and RLY1.

This grounds one end of L1 so that the oscillator will operate normally even without a DUT connected. The micro then measures the oscillator's free-running frequency, to be used in later calculations when a DUT is connected.

If DPDT switch S3 is in the "L" position, any component connected to the input terminals will be shorted out by RLY1 and therefore it won't affect cal-



ATMEGA BASED L-C-F METER

ibration. However, if S3 is in the "C" position, the external component will still affect the oscillator frequency, so during power-on, either leave the input terminals disconnected or place S3 in the "L" position.

DPDT switch S4 can be used to disconnect the oscillator from microcontroller IC1's pin 6 frequency measurement input and instead connect external frequency measurement socket CON1.

This allows it to measure the frequency of a signal fed into CON1 but note that this input is DC-coupled and it will need to have positive peaks of at least 3V to give accurate measurements.

When S4 is set to measure external frequencies, its other pole connects digital input PD1 (pin 3) to ground. This pin is configured by the software to have a pull-up current, so it will transition from a high to low voltage and the micro can detect this, to change its display accordingly.

The LCD is driven in 4-bit mode using digital outputs PB0-PB5 (pin 14-19). Its backlight brightness is fixed at a moderate level by the 470Ω resistor between the 5V supply and its pin 15 (backlight anode), while contrast can be adjusted using trimpot VR1.

Micro IC1 runs at 16MHz, as determined by crystal X1. This is important for accurate frequency measurements (and thus accurate LC readings).

The whole circuit is powered from a 5V DC supply, fed in externally at CON2.

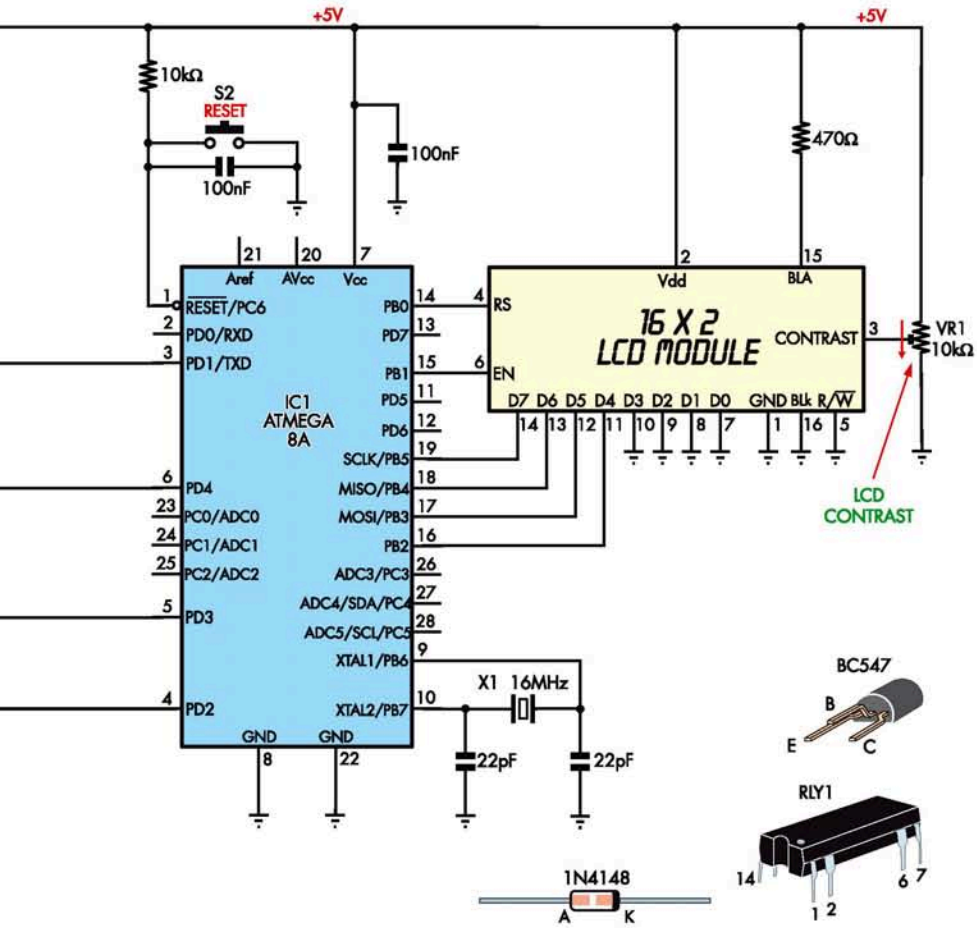
Be careful with the supply polarity as the circuit lacks protection against reversed polarity.

The reset pushbutton switch, S2, can be used to recalibrate the circuit manually. During calibration or recalibration the LCD reads "Calibrating..." on the first line and a bargraph in progression on the second line.

The software uses both hardware TIMER0 and TIMER1 for the frequency measurements. TIMER0 operates as a counter while TIMER1 is employed as a time reference, incremented by a clock derived from crystal X1.

The software is written using BASCOM and the files, named "ATmega LCF Meter.bas" and "ATmega LCF Meter.hex", are available for download from the SILICON CHIP website.

Mahmood Alimohammadi, Tehran, Iran. ($65)



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Micromite-based Colour Organ

This "colour organ" was designed to drive RGB LED strip modules that are available on eBay (search for "WS2812B").

These strips contain LEDs that are individually controlled by inbuilt WS2812 chips, allowing each LED to display one of 16 million colours. You can also use the Jaycar Arduino Compatible RGB LED Strip Module (Cat XC4380).

The LEDs in the strips are controlled so that their brightness and colour varies in time to music which is fed into the unit. If you choose to use multiple LED strips, the pattern travels down each strip over time, displaying a historical record of the sounds as colours – a time vs frequency vs amplitude display. With multiple LEDs strips, this can provide an impressive display.

The WS2812 in the LED strips uses a proprietary serial protocol which passes the data for its current colour to the next LED when new colour data is passed into it.

This means that many LEDs can be chained together and each is individually addressable.

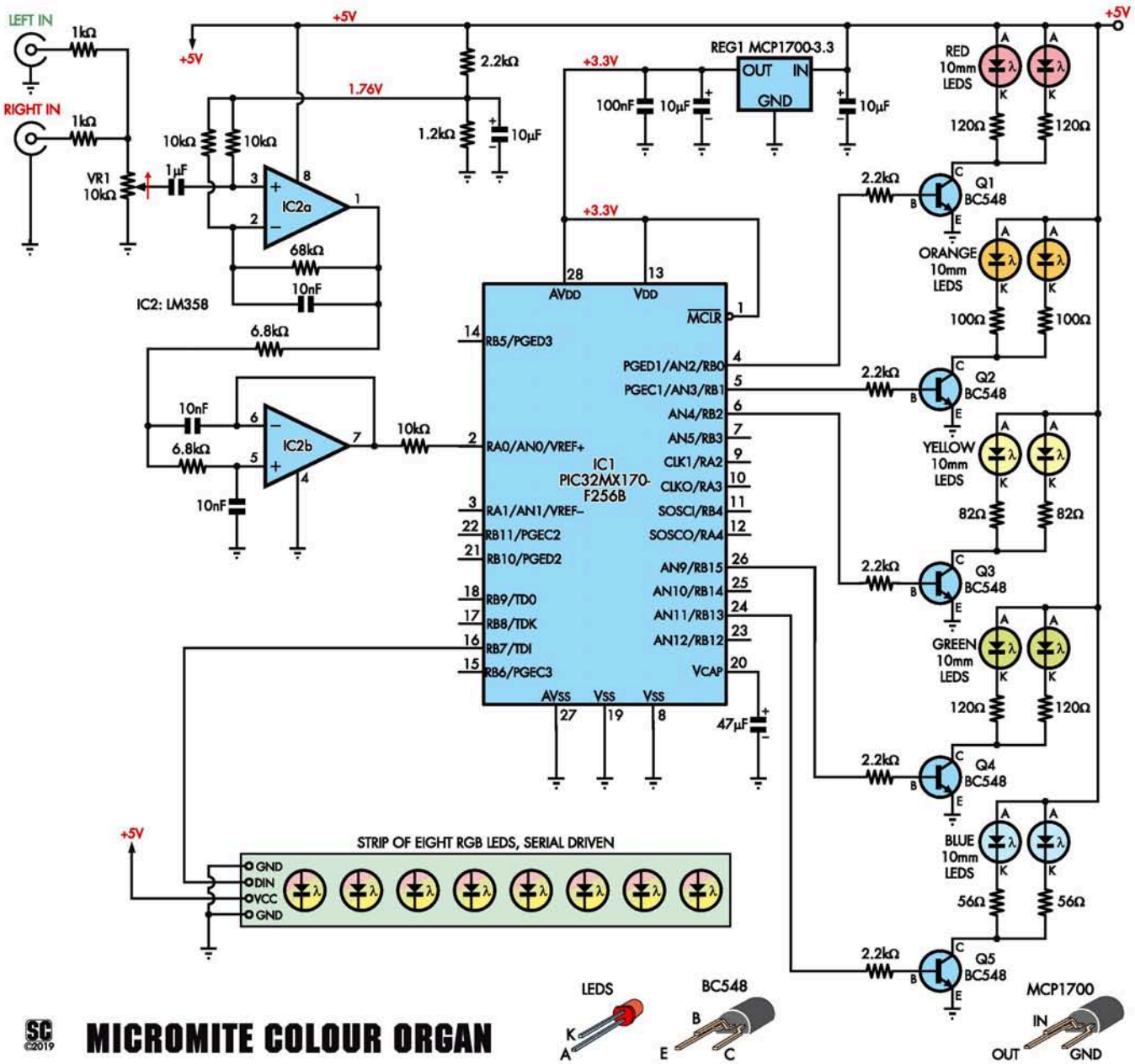
My display uses red to represent audio frequencies around 62Hz, then orange, yellow, green and blue to represent successively higher frequency bands for a total of eight bands.

It also has five separate PWM outputs to drive conventional LEDs, representing five audio bands. I have tested these driving high-brightness 10mm LEDs.

The circuit is based around a PIC32MX170 processor running MMBasic. The left and right channel audio signals are mixed together using 1kΩ resistors and then the level is adjusted by potentiometer VR1.

The signal is AC-coupled to the non-inverting input (pin 3) of op amp IC2a and biased to around 1.76V DC via a 10kΩ resistor.

The 1.76V DC reference is generated using a resistive divider of 2.2kΩ and



SC ©2019 **MICROMITE COLOUR ORGAN**

1.2kΩ across the 5V supply rail, with a 10µF filter capacitor to remove any supply ripple or noise.

The same reference voltage is used as the return point for the feedback network, which provides a signal gain of 7.8 times (68kΩ ÷ 10kΩ + 1).

The 10nF capacitor across the feedback resistor reduces the gain above 2.7kHz. The signal is then fed to op amp IC2b which forms a Sallen-Key second-order low-pass filter with a corner frequency of 2.7kHz.

This may seem low compared to the normal 20kHz upper limit used for music, but there is very little musical information above 3kHz.

What you get is a lot of harmonics or noise (eg, from percussion instruments) that adds richness to the sound, but the fundamentals are mostly below 3kHz.

The signal is then fed to pin 2 of microcontroller IC1 via a 10kΩ current-limiting resistor.

This pin is capable of being used as an analog input, to feed the micro's internal analog-to-digital converter (ADC). The software samples the voltage at this pin 4000 times per second (ie, a 4kHz sampling rate).

Technically the low-pass filter cut-off frequency should be 2kHz for 4kHz sampling rate, as the signals above 2kHz alias into the 1.3-2kHz band.

This flaw has been used to our advantage as it makes the highest band responsive to signals up to 2.7kHz instead of 2kHz; the data is being averaged by the software anyway.

IC1 provides software-driven PWM outputs at pins 4, 5, 6, 26 and 24 which drive NPN transistors Q1-Q5 via 2.2kΩ base resistors, to drive the five sets of colour LEDs.

Each different colour of LEDs uses different value series resistors to get reasonable brightness matching. These were chosen to suit Jaycar high-brightness 10mm LEDs.

If you want to drive more than two LEDs per output, you could change Q1-Q5 to BC337 types which can drive 10 or so LEDs in parallel.

Serial data for the RGB LED strips is produced at pin 16. The only other connections required for the LED strips are the 5V supply voltage and ground.

The software has three modes: 1) driving the LED strips only, 2) driving the individual PWM outputs, or 3) driving both.

On power-up the red LEDs driven by Q1 flash three times. To select the mode, switch on the power, wait for the flash for the mode (eg, the third flash indicates mode 3), then switch off the power. Switch the power back on again and leave it alone. It will still flash 3 times, but then it will remain in the selected mode each time you switch it on thereafter.

The Micromite software (written in BASIC) periodically samples the audio at input pin 2 64 times (at a 4kHz rate) and then feeds the data into a fast Fourier transform (FFT) subroutine. This returns 32 values representing the amplitudes of the sinewave components of this audio sample, equally spaced in frequency from DC to 2kHz.

The software uses CFUNCTIONS for the FFT and WS2812 drivers written by Peter Mather of The Back Shed.

Since the human ear's response to sound frequency is roughly logarithmic, the data is sorted into values that match human perception, with the lowest values at 62Hz and 125Hz being used directly to drive the outputs, while the upper values (eg 1.3kHz-2kHz) are averaged together.

64 samples may not sound like a lot but the problem with FFTs is that if you increase the number of samples to get better low-frequency resolution, you need to sample significantly more data and it takes longer to process.

After experimenting with a range of sample sizes from 32 to 512, I found that 64 gives the best compromise of speed and resolution.

Even though a lot of the code is in BASIC, the display still refreshes 16 times per second with 62Hz frequency resolution.

Reducing the FFT size to 32 brings the refresh rate up to about 25Hz, improving responsiveness (particularly of hi-hats) at the expense of resolution.

The data is sorted into eight groups for driving the LED strips and five groups for the LEDs driven by transistors Q1-Q5.

The circuit can be powered by a 5V plug pack and typically draws less than 100mA, so it can be powered by a discarded mobile phone charger.

The single BASIC file will be available from the SILICON CHIP Online Shop.

Dan Amos,
Macquarie Fields, NSW. ($75)

6V SLA Automatic Switchmode Solar Charger

This automatic switchmode solar battery charger is designed to suit 6V lead-acid batteries of around 4Ah. It uses commonly available 12V or 24V (nominal) solar panels.

It accommodates a wide range of panel voltages (9-30V) by using a step-down (buck) converter. This type of configuration has relatively low losses as it does not require a transformer, it just needs an inductor of around 30µH/5A. I measured the efficiency as 86% when charging a 6V SLA with a 9V DC input.

I decided to use a 6V lead-acid battery since they have a high capacity for the price and the charging scheme is quite simple.

It's based around IC1, the ubiquitous MC34063 switch-mode controller. It uses an external bipolar transistor, Q1 (TIP32) as the pass element for higher efficiency compared to using IC1's internal transistor.

Although the datasheet says that the MC34063 can switch currents up to 1.5A, in practice the IC becomes hot. The TIP32 has a high current rating so the saturation voltage is low and this improves the overall efficiency.

The 0.33Ω resistor between IC1's pins 6 and 7 sets the current limit of the converter to 400mA which allows us to charge a completely flat 4Ah battery in 10 hours.

The charging time is quite long but this ensures the plates of the battery will not buckle, which can happen with high charging currents.

It may take longer than 10 hours to charge depending on the size of the solar panels and how much light they are exposed to, while it will take less time if the battery is not fully discharged.

The 180Ω base resistor for Q1 was chosen to allow the TIP32 to saturate, ie, to act as a switch. The 330Ω resistor between its base and emitter ensures it switches off quickly once the base drive from IC1 switches off.

Schottky diode D1 is essential since the collector of Q1 will be pulled neg-

ative by the collapsing magnetic field in L1 when Q1 switches off. "Freewheeling" diode D1 ensures that it cannot go more than about 0.5V below ground, to prevent damage to Q1.

Schottky diodes have a very fast recovery time which is vital for good efficiency in a switchmode circuit.

The 5.1kΩ and 1kΩ resistors form a voltage divider which samples the output of the converter and feeds it back to IC1 so that it can regulate the output to around 7.6V, suitable for charging a 6V battery.

IC1 has an internal 1.25V reference and this is effectively multiplied by the divider ratio, ie, 7.6V ([5.1kΩ ÷ 1kΩ + 1] × 1.25V).

For a higher voltage, IC1 adjusts its output pulse width to be longer, resulting in a higher duty cycle. The duty cycle has an upper limit since a wide pulse width can saturate the core of inductor L1 which will cause a dramatic increase in current draw and a loss in efficiency.

Op amp IC2 (MC34072) is responsible for battery charge control. Another TIP32 PNP transistor (Q2) switches current flow from the output of the DC/DC converter to the battery.

When the output of op amp IC2a is high, NPN transistor Q3 is on, sinking current from the base of Q2 and so charging the battery via schottky diode D6. As with Q1, Q2's base resistor value is low, so it acts as a switch.

The inverting input of IC2a (pin 2) is connected to the battery via a resistive divider, so it has 43.4% of the battery voltage applied – ie, if the battery is at 6V, pin 2 of IC2a is at 2.61V.

The non-inverting input, pin 3, is fed from a TL431 adjustable voltage reference IC (REF1). The 1.8kΩ and 10kΩ resistors program it to produce 2.95V.

This means that, as long as the battery voltage is below 6.785V (2.95V × [10kΩ + 13kΩ] ÷ 10kΩ), the output (pin 1) of op amp IC2a will be high and so current can flow into the battery.

Once it reaches about 6.785V (2.26V/cell), pin 1 of IC2a goes low, switching off Q3 and Q2 and therefore charging stops.

When this happens, PNP transistor Q4 switches on as current can flow from its base, through the 4.7kΩ resistor to pin 1 of IC2.

This effectively shorts out the 1.8kΩ resistor between the cathode and adjustment pin of REF1, and as a result, the reference voltage drops to 2.5V. That means that the battery voltage must drop below 5.75V (2.5V × 23kΩ ÷ 10kΩ) (1.92V/cell) before charging will resume.

This arrangement has the advantage that the hysteresis and threshold voltages are independent of the battery and supply voltages.

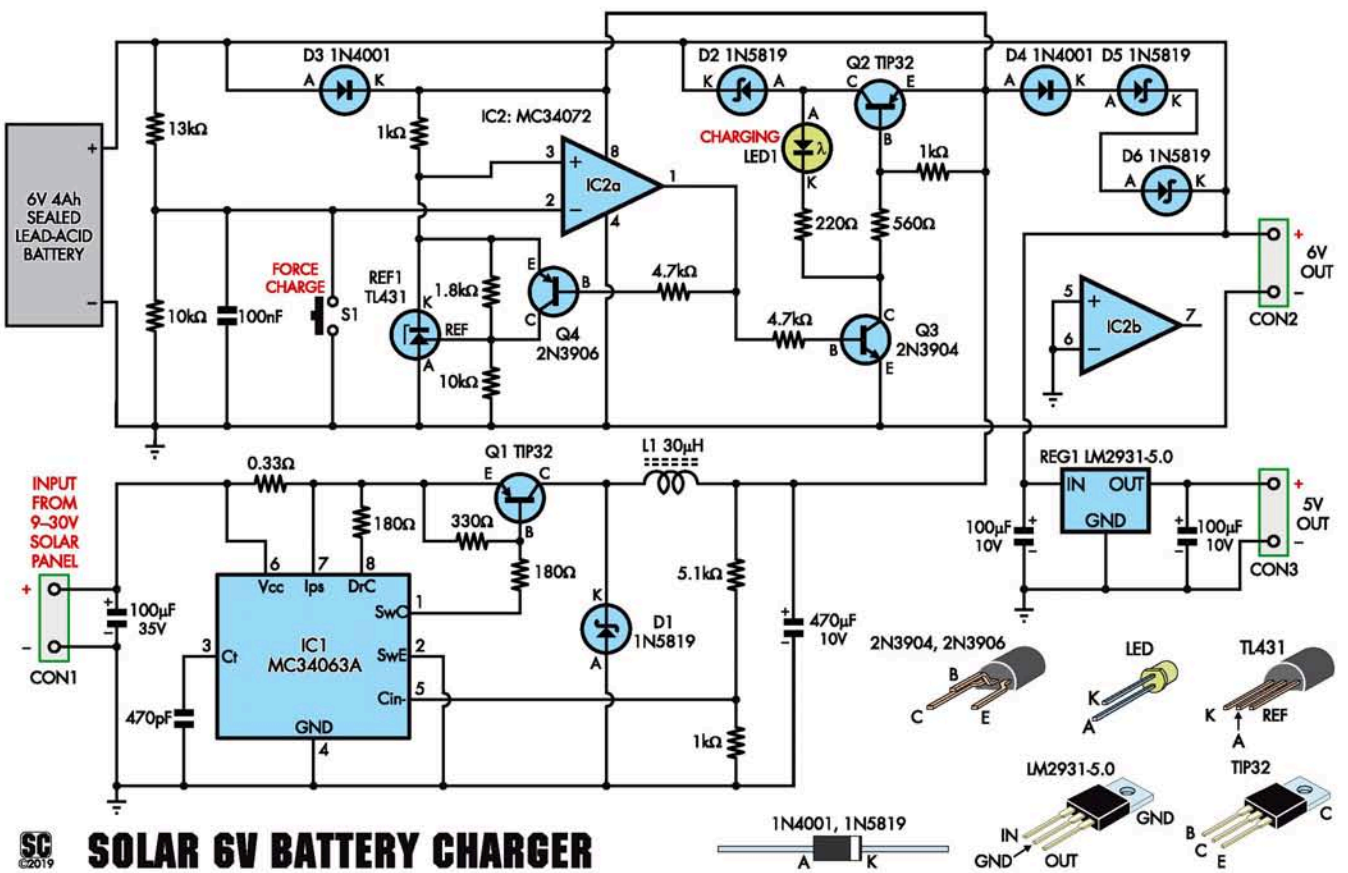
When transistors Q3 and Q2 are on and the battery is being charged, Q3 also pulls current through LED1, indicating that charging is taking place.

If the battery voltage is above 5.75V and the charger is off but you want to charge it, pressing S1 briefly pulls input pin 2 of IC2a low, forcing it to start charging. It will continue charging as long as the battery voltage is below the 6.785V threshold.

A separate 6V DC output is provided at CON2. Since the charging voltage is higher, standard silicon diode D4 and schottky diodes D5 and D6 are connected in series to drop the voltage, so it's closer to 6V.

This is regulated to 5V by low-dropout linear regulator REG1, to provide a convenient 5V output at CON3. But note that it has limited current delivery of 100mA maximum.

Noel Rios,
Manila, Philippines. ($90)



SOLAR 6V BATTERY CHARGER

ASK SILICON CHIP

Got a technical problem? Can't understand a piece of jargon or some technical principle? Drop us a line and we'll answer your question. Send your email to silicon@siliconchip.com.au

LED lights on dimmer flicker periodically

Recently, my daughter's home was renovated, and new lighting was installed by a licenced electrician. They now have multiple dimmable LED downlights in two rooms, four in each room, and each with a dimmer.

Your February 2019 article on your Trailing Edge Dimmer, by John Clarke, prompted me to contact you with this problem.

Around 8pm, the lights in these rooms flicker annoyingly for a minute or two. The lights are usually on for several hours before this with no flicker and the dimmers are not being adjusted at the time.

This issue was reported to the electrician by my daughter, and he answered that this was due to signals on the power. He suggested these could be due to DRED (DRM) signals or Off-Peak signals, and that an "expensive filter" could be installed to alleviate this problem.

My daughter did not take this option. This puzzles me as surely this is not the only house with this annoying problem in Australia.

I have not looked into this in detail as yet, but could this be due to an inappropriate dimmer that the electrician has installed, or is it a general problem being experienced out there and that someone is looking into for a resolution. Your feedback would be greatly appreciated. (B. C., Moss Vale, NSW)

● This is most likely due to the dimmer failing to filter out the mains control tones in its zero crossing detector. That suggests a poor dimmer circuit design. Perhaps your electrician could swap the dimmer for one that does not have that failing.

It would be possible to install a filter to remove the control tones from that circuit, but it should not be necessary.

Our recent Trailing Edge Touch & IR Remote Control Dimmer design (February & March 2019; siliconchip.com.au/Article/3750) does not have this shortcoming so there must be commercial models out there which can adequately reject the control tones.

Unfortunately, you may need to try a couple of different LED-compatible dimmers before you find one that isn't affected by control tones, which likely means some more visits from your electrician.

High power audio amplifier module

Have you produced any amplifier module designs that could be used to substitute for the boards in a Peavey PV-8.5C 2x550W amplifier?

It appears to have ±82V DC supply rails, and this one is in a rather sad state. The case and the rather massive transformer look useable, though. I might get it all going yet, but if I can't, I may need to build replacement amplifier modules. (A. S., via email)

● We published a design in August-September 1997 which is almost ex-

Some touchscreens have reversed touch panels

I recently purchased the kits for your Lab Quality Programmable GPS-Synched Frequency Reference unit and now that all boards are populated, I powered up the unit using a different GPS unit (Neo-6M-0-001) that has a facility to use an external powered antenna. I am using a tried-and-tested antenna that works with all my other GPS units on my test bench.

Having powered it up, I found that quite a few of the on-screen buttons do not work and there are some fluctuating frequencies at the 3 BNC sockets as measured on my HP 5335A meter.

Try as I may, no manner of manipulations of the status button using the stylus lets me get into that screen. I hope this is not due to a software bug.

I have been building surface mount boards and populating them for many years now, so I tend to believe the hardware side of the construction is OK but who knows. Any help/advice will be appreciated. (M. T., Woodvale, WA)

● Some of the new 2.8-inch LCD touchscreens we are receiving from suppliers these days seem to have a different touch sensor calibration to the original screens we used.

This means that the touch calibration in the pre-loaded software does not work correctly 'out-of-the-box'. You need to issue a "GUI CALIBRATE" command and follow the prompts to calibrate the unit for the different screen.

The screens with differing touch sensor calibration seem to be the ones that come with a stylus. At least one of the touch axes is reversed! Regardless, this is fixed by a re-calibration. Other screens we receive still work with the default calibration, so we're loath to change it.

Note though that with this project, since OPTION BREAK 0 has been set (as otherwise, the 40MHz signal on the RX pin would reset the unit), it's not possible to break out of the GPS Frequency Reference software to get back to the Micromite terminal.

The solution to this is to start with a blank Micromite (reload the Micromite firmware to reset the Micromite) and set up the Micromite with the following commands:

```
OPTION LCDPANEL ILI9341, L,
  2, 23, 6
OPTION TOUCH 7, 15
GUI CALIBRATE
```

Then perform the "GUI TEST LCDPANEL" and "GUI TEST TOUCH" commands to check that the display and touch panel are working.

actly what you require: a 500W amplifier module which runs from ±70V DC supply rails (siliconchip.com.au/Series/146).

That design is still valid and all the components are still available, including the MJL21193 and MKL21194 output transistors. Your existing power supply is suitable.

The problem with this is that there is no longer a source of PCBs for that project but perhaps you can etch one yourself, using the PDF pattern download from our website.

Alternatively, you could modify the Studio 350 amplifier module design from the January and February 2004 issues (siliconchip.com.au/Series/97). Jaycar still has a kit for that project, Cat KC5372.

You would need to replace the MJE15030 and MJE15031 transistors with similar, higher-voltage transistors and you would also need to replace the 2SA1084 (90V) with a 2SA1085 (120V) or similar. The other components seem OK for ±82V.

Problems loading DDS IF Alignment software

A few months ago, I purchased a Micromite LCD BackPack kit from your Online Shop, programmed for the DDS Radio IF Alignment project. I have not been able to make it work. When I power it up, the display makes a horizontal and vertical sweep and then stays black without displaying shapes or colours.

I have replaced the display and the AD9833 DDS module with programmable attenuator, however, it keeps doing the same thing over and over again, so I suspect that the Micromite is defective.

On your advice, I purchased a CP2102 USB/serial adaptor and tried to use this to re-load the IF Alignment BASIC code ("DDSIFAlign.bas"). When I uploaded this using MMEdit, I got the message "Not enough memory". But I was able to successfully upload "SigGenerator.bas" (the software on which the DDS IF Alignment code is based) and it then worked!

Do you know why I'm getting this out of memory error? (M. R., Mexico City, Mexico)

● That's a strange problem. When we developed and tested the software, we did not get a "Not Enough Memory" error. We don't know why you are getting that now, with the same software and presumably identical hardware.

We investigated further and we were able to get the same error message as you upon uploading the code, but not consistently!

Since the program is close to the memory size of the Micromite, it appears that under some circumstances, it runs out of memory while being programmed.

To solve this, we have split the code into two separate files, one of which can be compressed by the Micromite, thus freeing up valuable memory. To install the new firmware, use the following steps:

1) In the MMedit console, run the "new" command to ensure the flash is clear.
2) Open the file "DDSIFAlign Fonts Only.bas" and upload the code to the Micromite.
3) In the console, issue the "library save" command. This compresses the font data.
4) Now open the "DDSIFAlign No Fonts.bas" file, and upload it.
5) Issue the "run" command from the console.

Majestic loudspeaker cabinet volume

I have some questions about the Majestic loudspeaker design published in the June and September 2014 issues (siliconchip.com.au/Series/275).

How did you calculate the dimensions of the speaker cabinet? Were the speaker specs taken from etone's specification sheet or did you measure the drivers yourself?

Why do you think the Celestion FTR15-4080FD woofer would be suitable in the same cabinet, given that its specifications are different? (R. C., Baulkham Hills, NSW)

● We asked the designer, Allan-Linton Smith and his response is: there's no simple answer to these questions because the design and development of the Majestic speakers took over two years and many calculations were made based off manufacturers' data, measured data of bare drivers and drivers in various different cabinets, and many listening tests.

It was a hard slog, and we did heaps of testing and tweaking, as the SILICON CHIP staff will no doubt be aware, as they were involved in some of these tests.

Having selected the etone 1525 woofers due to their performance and value for money, the only problem was their very high specified VAS (564 litres) which required a ported box of around 200 litres.

The initial cabinet dimensions were calculated using: siliconchip.com.au/link/aanm This is a very basic box calculator but was good enough to help me decide to use the Kaboodle kitchen cabinet to make construction easier and as a bonus, it looks good too, with a dozen colour and finish options.

Starting with this, after years of trial and error (including prototypes that SILICON CHIP rejected as being not good enough!), I finally discovered the Majestic formula which was finally published.

The alternative Celestion FTR15-4080FD woofer has a similar resonance and sensitivity but a much lower VAS, so it does not really need a 200L enclosure, but it is always best to go larger than smaller.

Of course, we made measurements and performed listening tests with both woofers before recommending them. While we still think the etone woofer sounds better, the Celestion woofer gives a decent sound.

The Celestion driver is also more expensive than the etone 1525, but it has three times the power handling (up to 1000W RMS)!

Using a theremin near a steel structure

A few years ago, I built the New, Improved Theremin Mk.2 from the March 2009 issue of SILICON CHIP magazine (siliconchip.com.au/Article/1368), from a Jaycar kit (Cat KC5475).

My plan was to incorporate it into a steel Meccano structure. I built it and plugged it and only to discover it did nothing. No sound at all.

A bit of head scratching revealed that Q4, a BC548 transistor was reversed. I should have noticed that all the transistors faced the same way.

After replacing it, I turned the power on again and could hear a very faint sound that could be altered by moving my hand around the antenna, but it was obviously not right.

The instructions spell out the procedure by telling you to wind the slugs of the IF coils until there is resistance. I couldn't really feel any resistance to rotation on some of the coils but I

Valve Preamp PCB/circuit discrepancy doesn't affect operation

I bought a couple of back issues of SILICON CHIP magazine and I am now reading the November 2003 article titled "The project we swore we would never do... A VALVE PREAMP". The circuit diagram of the valve preamp is shown on page 30 and the PCB layout is shown on page 32.

Regarding the feedback resistor string consisting of three 680kΩ 1W resistors, a 220kΩ and 47kΩ resistor and a 100kΩ trimpot, I noticed a discrepancy between the circuit and PCB design.

The circuit shows the trimpot at the bottom of this divider string, connecting directly to the ground rail.

But on the PCB, the 220kΩ resistor connects to ground with the trimpot then connecting to it and thence to the remaining resistors in the divider.

Can you tell me which is correct, the circuit diagram or PCB? I want to check this before I etch a PCB. (J. H., Scotland, UK)

● You are right that the circuit diagram and PCB pattern do not show the same thing; however, both configurations provide the same function.

Either way, trimpot VR1 is in series with the 220kΩ resistor and provides a means of changing the resistance of the bottom leg of the voltage divider, thus adjusting the power supply's output voltage.

So, if you etch a PCB from the pattern we published, it certainly should work.

We have updated the circuit diagram in our online issue to match the PCB configuration shown.

could see the voltages change at the test points. Nothing seemed to get the voltage on TP3 up to 7V. The highest I could get was 2V.

After months of trying to get it to go I gave up, but a couple of years later, I ran into your Vintage Radio contributor Rodney Champness. He gave me some suggestions on getting my Theremin working.

I brought out the Theremin to do some further troubleshooting and to my surprise, the faint whistle suddenly became a very loud adjustable squeal when I touched the slug of T3.

This is the white IF coil and now I remembered the difficulty I had finding its endpoints when turning the slug. I thought that maybe there was a dry joint, or perhaps the coil itself was faulty, so I purchased a new one to replace it.

After doing that, turning the slug revealed definite endpoints. Upon power-up, I was delighted to hear the unmistakable sound of Dr Who.

After adjusting all the coils, I had the correct reading of 7V at TP3 and a very likable sound coming out of the speaker.

Unfortunately, the volume plate still had little effect, so this project is still on the bench. I will set about building it into a Meccano box before I retune it and tweak the volume.

I pulled the metal cap off the faulty coil and discovered the slug screwed into a plastic cube and the threads inside were stripped. Maybe I'd screwed it out too far and stripped the thread but I doubt I would have used any force on such a small electronic component.

Can you suggest how I can get the volume control working properly? Even as it is, the sound is so very cool! Also, do you think the steel in the Meccano structure will prevent it from working, once it's in place? (J. B., Benalla, Vic)

● If you carefully follow the instructions in the Theremin article regarding adjustment of the volume range using the plate, you should be able to get that section working.

It would be best to do that before installing it in the metal Meccano case; otherwise, you will not know if it is the case or adjustments that prevent the volume plate action from working.

Is it legal to build your own mains-powered equipment?

I live in Western Australia and would like to know more about laws regarding working on projects involving 230VAC mains power. Do I need to be a qualified electrician to build mains-powered kits or are there provisions allowing for this? (R. L., Bedford, WA)

● John Clarke replies: as far as we are aware, the construction of a mains-operated project comes under the heading of manufacturing, where the electrical wiring has to comply with the wiring standards required for mains voltage safety.

For our projects, provided that the project is built exactly as per our instructions, the project should be deemed safe. In other words, you are following our instructions to complete the wiring in a way that complies with the standards.

If you are unsure, have your completed unit checked and tested by a licensed person (test and tag person or electrician) to ensure it complies to the safety requirements. Note that the tagging of a tested item is only required for appliances used at workplaces, not in the home.

For Western Australia, the guide to test and tag can be viewed at: http://siliconchip.com.au/link/aani

Regarding manufacture of equipment, the following link (for Queensland, but we expect WA legislation to be similar) has the details in section 2d (http://siliconchip.com.au/link/aanj):

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We are not sure what effect the Meccano case will have on the Theremin operation. It may not affect the pitch control but may prevent the hand plate (volume control) from working.

The plate needs to be mounted away from the metal Meccano case. Both the pitch antenna and volume plate also need to be electrically isolated from the Meccano metallic case.

Modifying Do Not Disturb Timer for NBN

I built your Do Not Disturb Phone Timer (May 2013; siliconchip.com.au/Article/3776) and it has worked well for some years for my parents, who could enjoy an undisturbed afternoon nap when using it!

Recently, it has stopped working intermittently; they sometimes could not set/start the timer. Every time I tested it, it worked fine.

I did some measurements at home and at my parents' house and found that my home phone line sat at around 48V DC with the phone on the hook and around 8V DC off-hook, while my parents only had 14V DC on-hook.

I have a standard PSTN phone line whilst my parents have had FTTP NBN since mid-2015. The timer initially worked OK on the NBN phone line but now doesn't work at all.

The problem is apparently because the NBN phone line voltage is so much lower than the PSTN phone line voltage. Given this low voltage, it's a wonder that the timer ever worked on the NBN phone line. Can you suggest any modifications to the circuit so that the timer will work at the lower NBN phone line voltage? (M. G., Duncraig, WA)

- Try changing the 100kΩ resistor supplying 5.6V zener diode ZD1 to 15kΩ. That should allow IC1 to run at around 5V DC.

You may need to experiment with the two 180Ω resistors between the collector of Q2 and circuit ground. These need to be low enough to place the line 'off-hook' but not so low that the phone line voltage drops too low. The supply to IC1 should be kept above 4V DC.

How to tell if anti-fouling is working

I built your New Marine Ultrasonic Anti-Fouling Unit described in the May and June 2017 issues (siliconchip.com.au/Series/312) from a Jaycar kit, Cat KC5535. How can I verify the operation of the transducer? The neon lights and the unit does not indicate any errors.

- The fact that the neon lights up indicates that the ultrasonic transducer is being driven. There is no easy way to check that the transducer itself is working; the primary indication is the reduced growth on the boat hull.

You can use another ultrasonic transducer as a receiver to monitor the sound from the driven transducer, by resting the face of one on the face of the other, but you need an oscilloscope to observe the receiver transducer waveform, which appears across its terminals.

Increasing Arduino Seismograph sensitivity

I recently built your 3-Axis Arduino Seismograph project (April 2018; siliconchip.com.au/Article/11030) using an Arduino Nano.

It is up and running and producing data, but I want to increase the sensitivity of the system.

The datasheet says that the accelerometer defaults to its most sensitive range of ±2g. Is there a way of increasing the sensitivity beyond this? I am using the project to collect vibration data from under my house before the Westconnex tunnelling. I want to have data to create a baseline.

Alternatively, how much amplification can be applied in Audacity to read smaller values? (S. S., Rozelle, NSW)

- The accelerometer in the Seismograph is set to use the ±4g range as noted on page 27 of the article (Specifications). This is set in the code by the line (383 in the current version):

```
// set hi pass and scale
Wire.write(
   MPU6050_ACCEL_HPF_0_63HZ |
   MPU6050_AFS_SEL_4G);
```

You can increase the sensitivity by changing MPU6050_AFS_SEL_4G to MPU6050_AFS_SEL_2G. The data from the accelerometer is 16-bit, and recorded in the WAV file as 16-bit, so you aren't going to get any more sensitivity than this using this part (the MPU-6050).

The data can be amplified as much as you like in Audacity, although the practical limit is about 1000 times.

You would already be reading tiny acceleration figures of around ±00006g, and these readings will be 'down in the noise'. We're not sure that increasing the sensitivity any further, even if you could, would give any meaningful readings.

Running bilge pump from a solar panel

I have a situation where I need to power a bilge pump with solar panels. The pump is remotely located and needs to operate intermittently, as dictated by rising water levels.

No mains power is available and I want the system to be simple and maintenance free, so I propose to use solar panels as the only power source. The pump is rated at 12V, 3.5A and has a float switch.

Finding solar panels is not a problem, but looking at their specs, I notice that most have a no-load voltage in the region of 20V, dropping to approximately 12V when a load is applied. What concerns me is, if the float switch operates applying a no-load voltage of 20V directly to the pump motor, will this burn out the pump motor?

I want to avoid the use of batteries. How can I connect the solar panels to the pump motor safely? Do I need a voltage regulator? (S. R., via email)

- You should be able to run the pump directly from a 40W 12V solar panel. The open circuit voltage shouldn't cause any problems since the current draw when connected to the pump will cause the solar panel voltage to drop substantially.

The insulation on the motor should be capable of withstanding 20V briefly, until the voltage stabilises at a lower level.

A panel with a power rating higher than 40W could cause the pump to burn out, due to operating at a higher voltage.

For example, a 60W panel can supply 3.5A at 17V, its maximum power point. At this voltage, the pump will draw more than its rated 3.5A and the panel voltage will drop, but probably not enough to avoid the pump burning out over time.

It would be best to try a panel before you buy one to be sure the motor voltage is around 12V when the panel is in full sun and pumping the head of water expected of the pump. That should be a safe condition for long-term operation. SC

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Coming up in Silicon Chip

Altium Designer 19 review
Hot on the heels of the major update that was Altium Designer 18 comes this new major version of this Australian electronics computer aided design (ECAD) software.

El Cheapo Modules – LoRa long-range digital modules
These low-cost modules allow microcontrollers to communicate with each other even when they are hundreds of metres apart, or in some cases, even kilometres. And they're pretty easy to set up and use, too.

Facial Recognition Systems
Is Big Brother watching us now? Facial recognition systems are already in use by Australian government agencies. Dr David Maddison explains how computer-based facial recognition systems are able to identify individuals in still photos, video and even in real-time. He then takes a look into the applications of such systems, both beneficial and nefarious.

Flip-dot display
This is one of the more unusual electronics projects that we've come across. It's a dot matrix display that's highly visible in just about any lighting condition and it's driven by electromagnets formed from PCB tracks! It could be used in a practical outdoor alphanumeric display or a fun indoor display.

High-current linear bench supply
This power supply has very low ripple and noise due to the use of linear regulation. But it can still deliver plenty of current (>5A) with an output of up to 50V.

UHF repeater
Based on reader requests, this device extends the range for devices such as our 2015 Driveway Monitor which use UHF transmissions to send data from a remote unit to a base station. It can both extend the usable range and also solves line-of-sight problems caused by hills or obstacles that are in the way of the signal.

Note: these features are planned or are in preparation and should appear within the next few issues of Silicon Chip.

The April 2019 issue is due on sale in newsagents by Thursday, March 28th. Expect postal delivery of subscription copies in Australia between March 26th and April 12th.

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Notes & Errata

Tinnitus & Insomnia Killer, November 2018: there is an error in both versions of the PCB. The 68kΩ resistor in the Pink Noise Filter (above and to the right of IC1) is connected to the wrong end of the 1kΩ resistor immediately next to IC1. This results in the pink noise being slightly louder than intended. This error will be corrected on RevC PCBs. If you have a RevB PCB, you can fix it by cutting the bottom layer track between the nearest pads of these two components and wiring the now free end of the 68kΩ resistor to the opposite end of the 1kΩ resistor using a short piece of insulated wire.

Stationmaster Walkaround Model Rail Controller, March 2017: two 10MΩ resistors have been left off the circuit diagram, Fig.2. One connects from the +5V rail to pins 10 & 13 of IC1 while the other connects from pins 10 & 13 of IC1 to ground. The PCB overlay and parts list are correct. Also, because power indicator LED1 is connected to the supply before the bridge rectifier, it will only light with a DC supply that applies a positive voltage to either pin 1 of CON1 or the centre pin of CON2. On page 37, instead of 10kΩ capacitor, read 10kΩ resistor. Also, the cable connecting the two boards needs to be the type with its inner two conductors swapped or else speed control VR2 will operate in reverse. Finally, note that the MC14584 chip used in this project is hard to obtain; the more common 74HC14 can be substituted.

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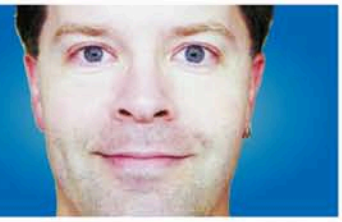

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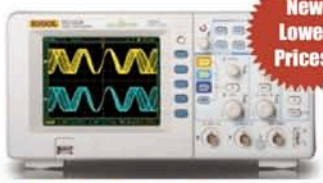

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